UiT The Arctic University of Norway

Master`s thesis in Geology

Geochemical characteristics of sediment- and mafic rock-hosted Cu deposits in the Kåfjord area, Alta-Kvænangen Tectonic Window, Northern Norway

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- Supervisor: Sabina Strmić Palinkaš
- Co-supervisor: Harald Hansen

Mineral Exploration Targeting

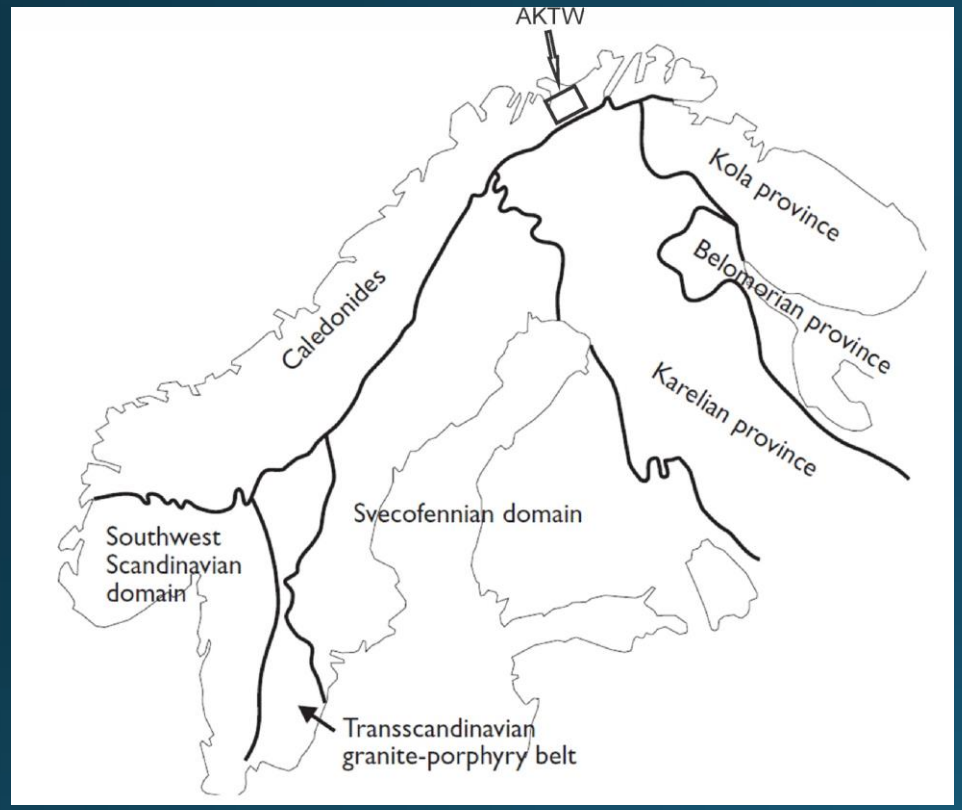
eit RawMaterials Connecting matters

Goal of the study

- The main goal of this master project is to determine the mineralogical, geochemical, and stable isotope characteristics of the ore mineralization, host rocks, and alteration products of the sediment-hosted and mafic rock-hosted Cu mineralization in the Kåfjord area of AKTW.

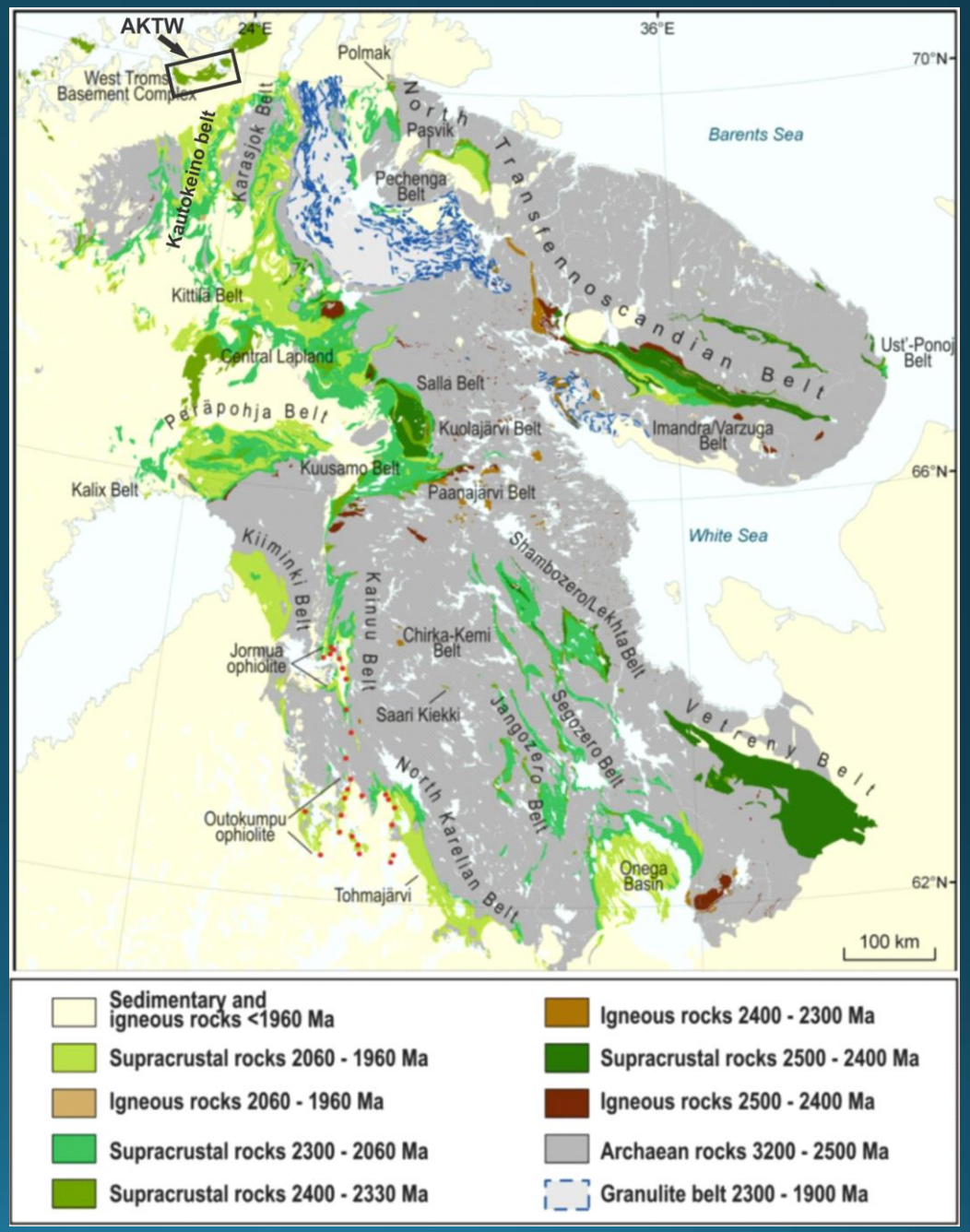
Introduction

Geological setting



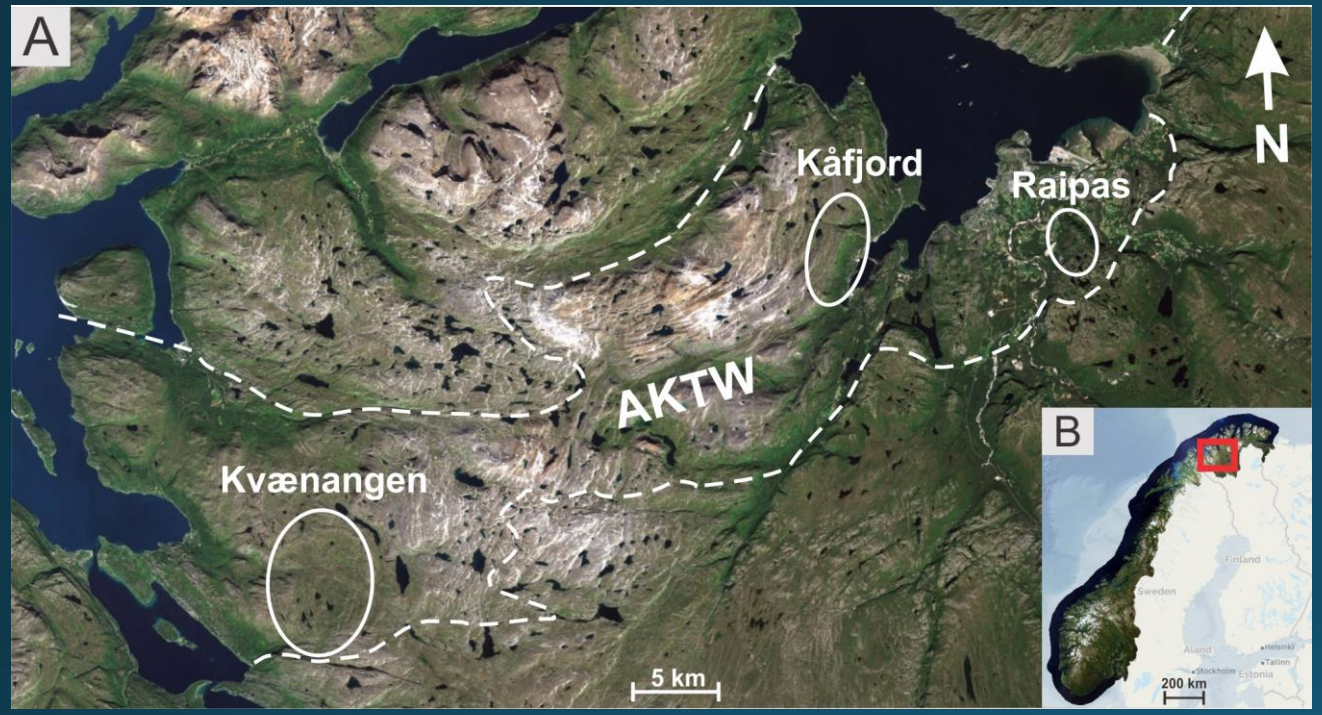
Modified after Lahtinen et al. (2005), based originally on Gaal and Gorbatschev (1987).

- Tectonic window
- 2300-2060Ma



Modified after Melezhik et al. (2013), based originally on Koistinen et al. (2001).

Geological setting



Orthophotos are downloaded and modified from Norge i bilder (2021).

Mining activity

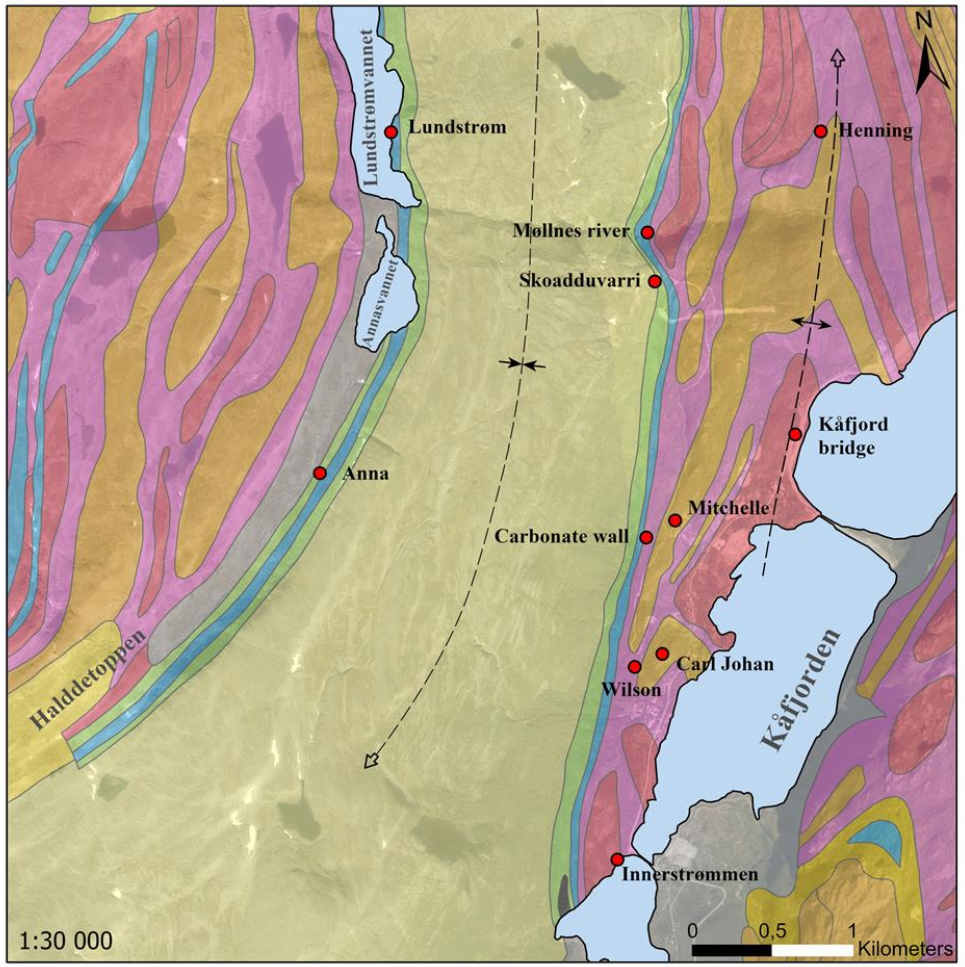
-> In two periods within 1827 to 1909

-> Kvænangen, Kåfjord and Raipas

Localities at Kåfjord

-> 14 wheras 7 are historical mines

Orthophoto is downloaded and modified from Norge i bilder (2021).



Legend

- Localities

Bossekop Group
- Quartzite

Raipas Supergroup

Skoadduvarri formation
- Sandstone with layers of shale and conglomerate

Storviknes formation
- Dolomite and limestone
- Shale

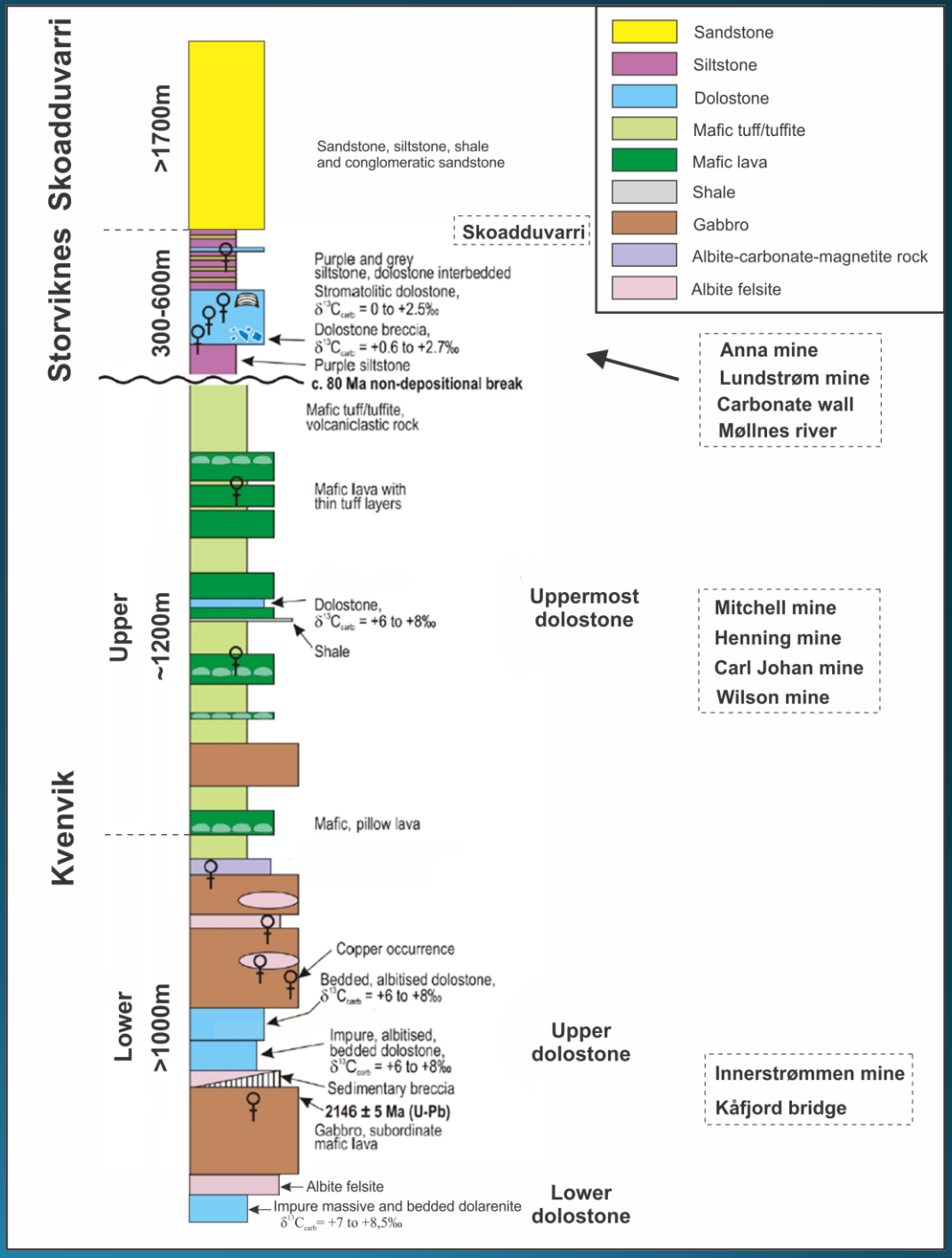
Synclinal trend — Anticlinal trend

Kvenvik formation
- Metagabbro
- Metagabbro with layers of basaltic tuff
- Metabasalt
- Metabasalt with pillowstructures
- Metabasalt with layers of tuff
- Basaltic tuff and tuffite
- Basaltic tuff and tuffite with layers of shale

- Not classified
- Covered (mostly sand og gravel)
- Water

1:50 000 bedrock map from NGU (2021b) *overlain an orthophoto from* Norge i bilder (2021). *The synclinal and anticlinal trend has been added after* Bergh and Torske (1988).

Modified after Melezhik et al. (2015), based originally on Vik (1985).



Types of mineralization

Mafic rock-hosted Cu deposits

- Syngenetic stratiform mineralization (VMS)
- Copper as dissemination in host-rock
- Cu-barren epigenetic quartz-carbonate veins
- Cu-bearing epigenetic quartz-carbonate veins

Sediment-hosted Cu deposits

- Cu-bearing epigenetic quartz- carbonate veins

Methods

- Field sampling in Kåfjord
  -> 10 days

- Transmitted and reflected polarized light microscopy
- Scanning Electron Microscopy - Energy Dispersive System (SEM-EDS)
- Laser Ablation - Inductively Coupled Plasma - Mass Spectrometer (LA-ICP-MS)

- Whole rock geochemistry

- Carbonate isotope ($\delta^{18}O$ and $\delta^{13}C$)
- Sulfur isotope ($\delta^{34}S$)

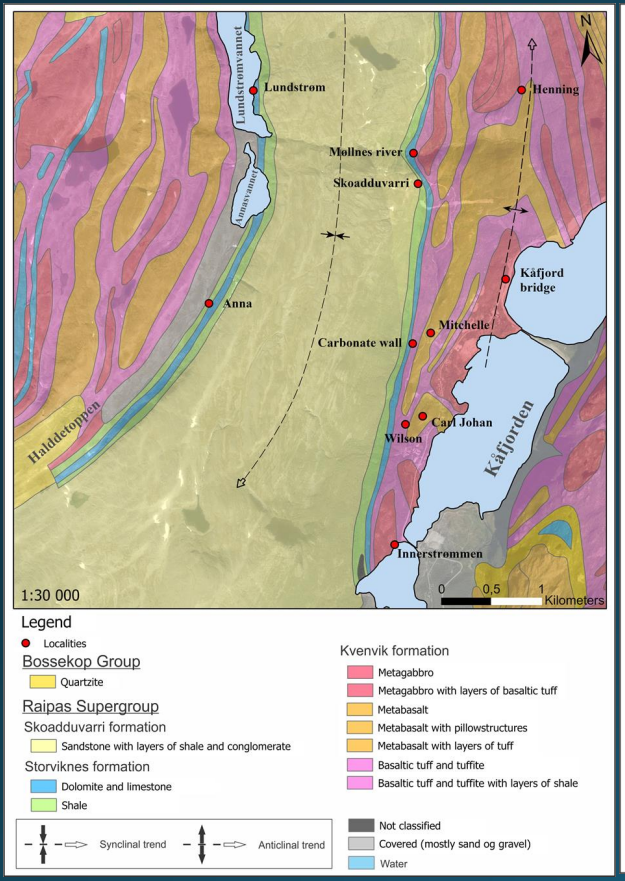
- Fluid inclusion study

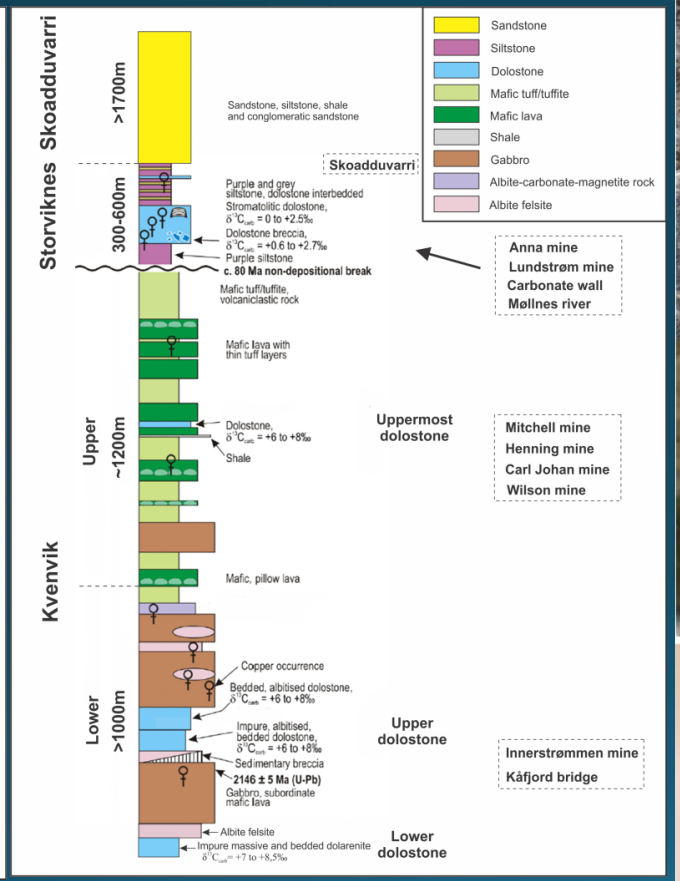
Results and discussion

Mafic rock-hosted

Cu-barren epigenetic quartz-carbonate veins

Kåfjord bridge
(Gabbro hosted)



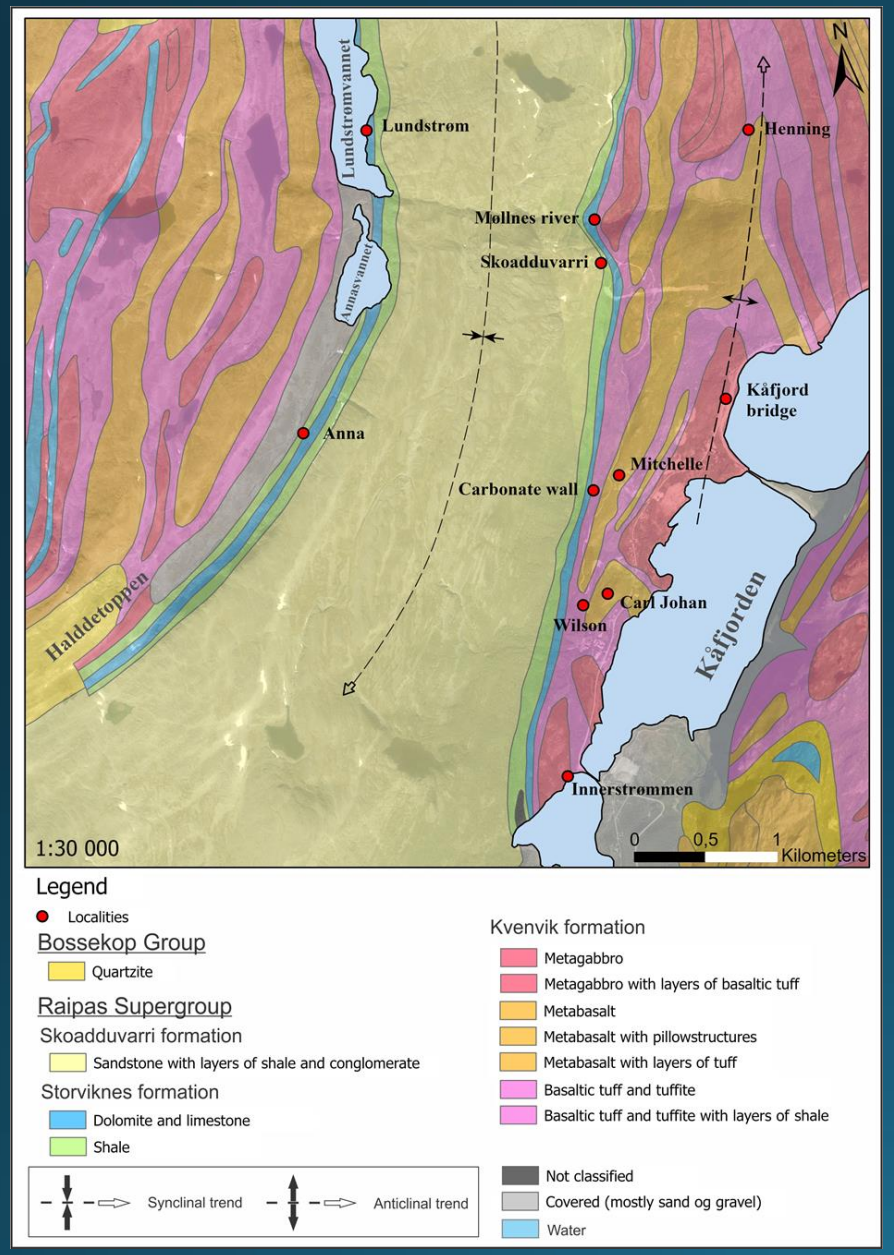


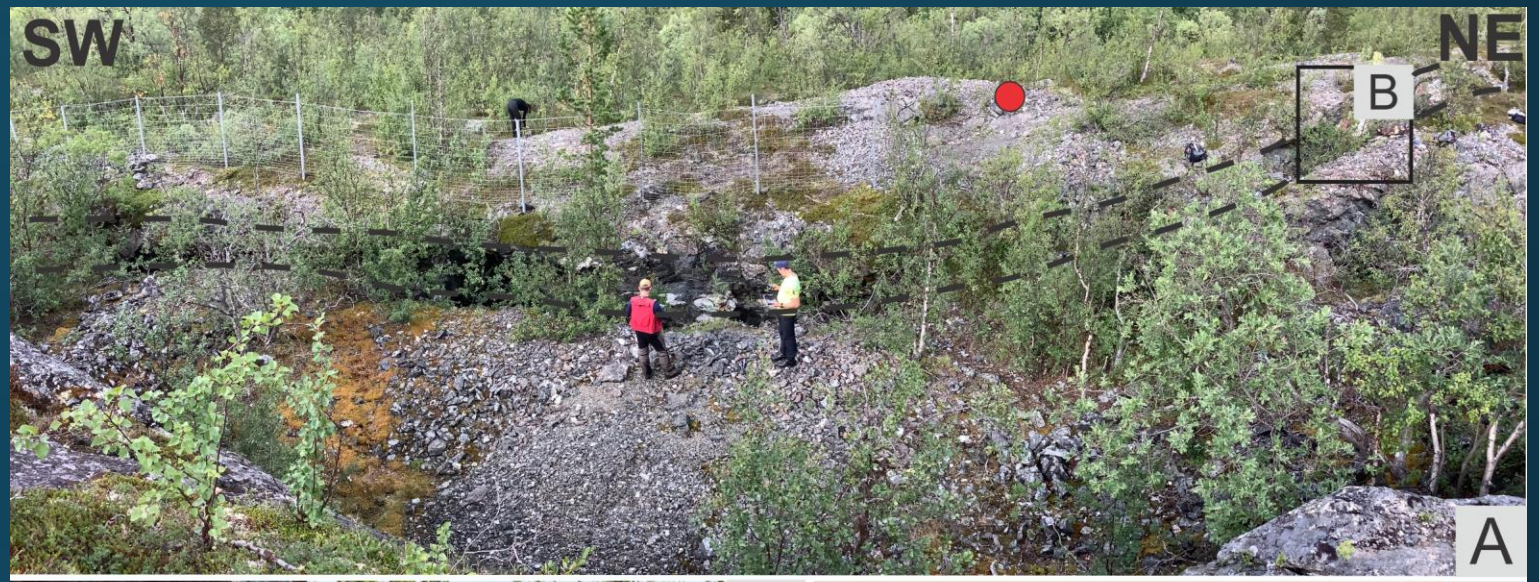
Mafic rock-hosted

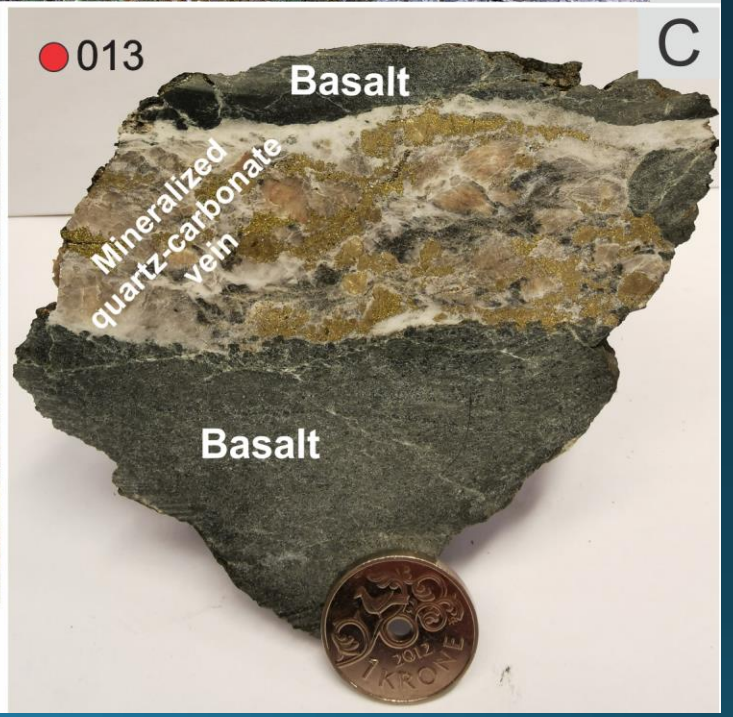
Cu-bearing epigenetic quartz-carbonate veins

Carl Johan mine

(Basalt hosted)

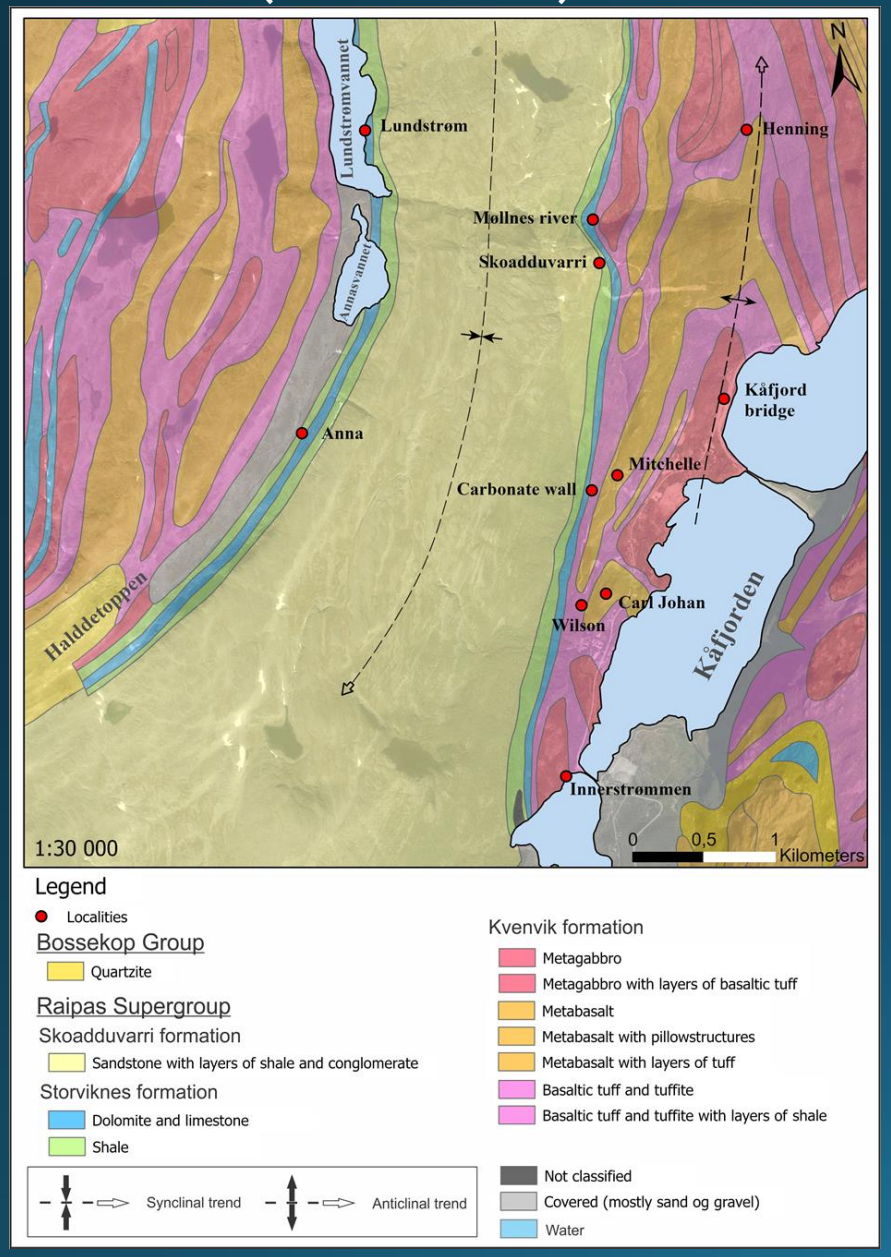






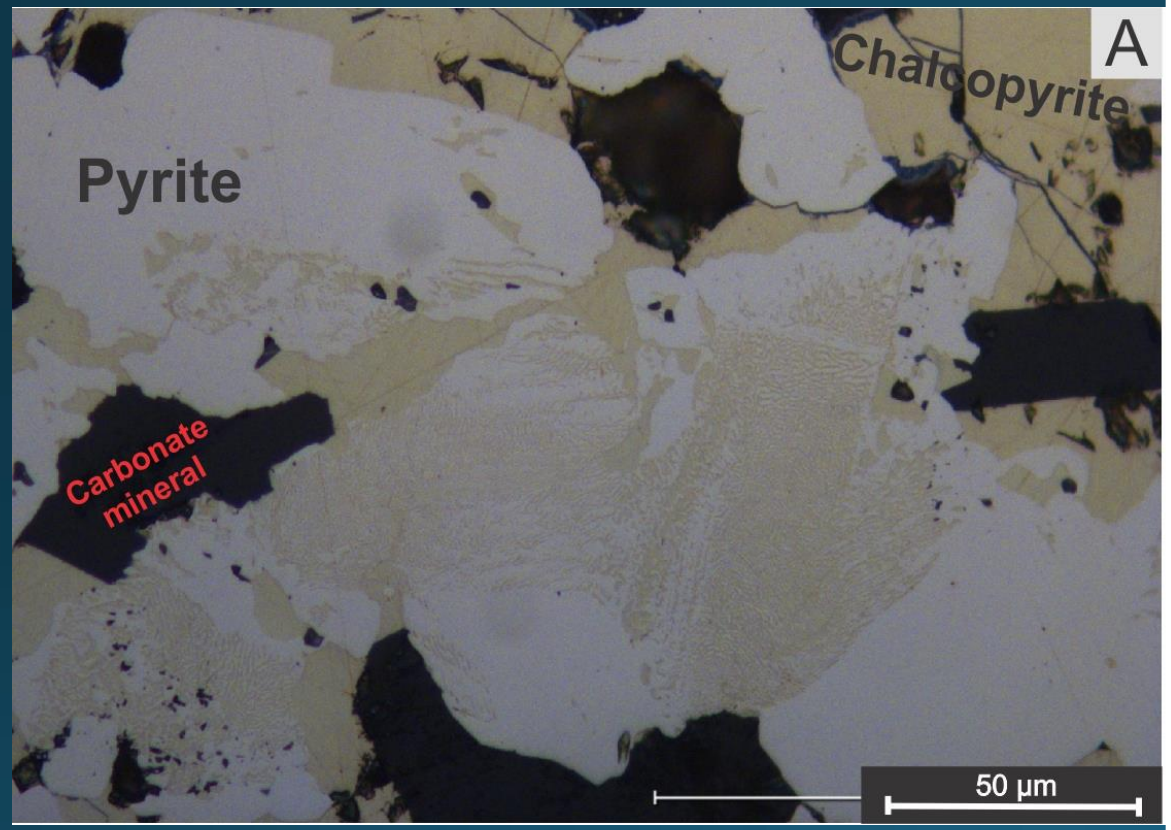
Mitchell mine

(Basalt hosted)



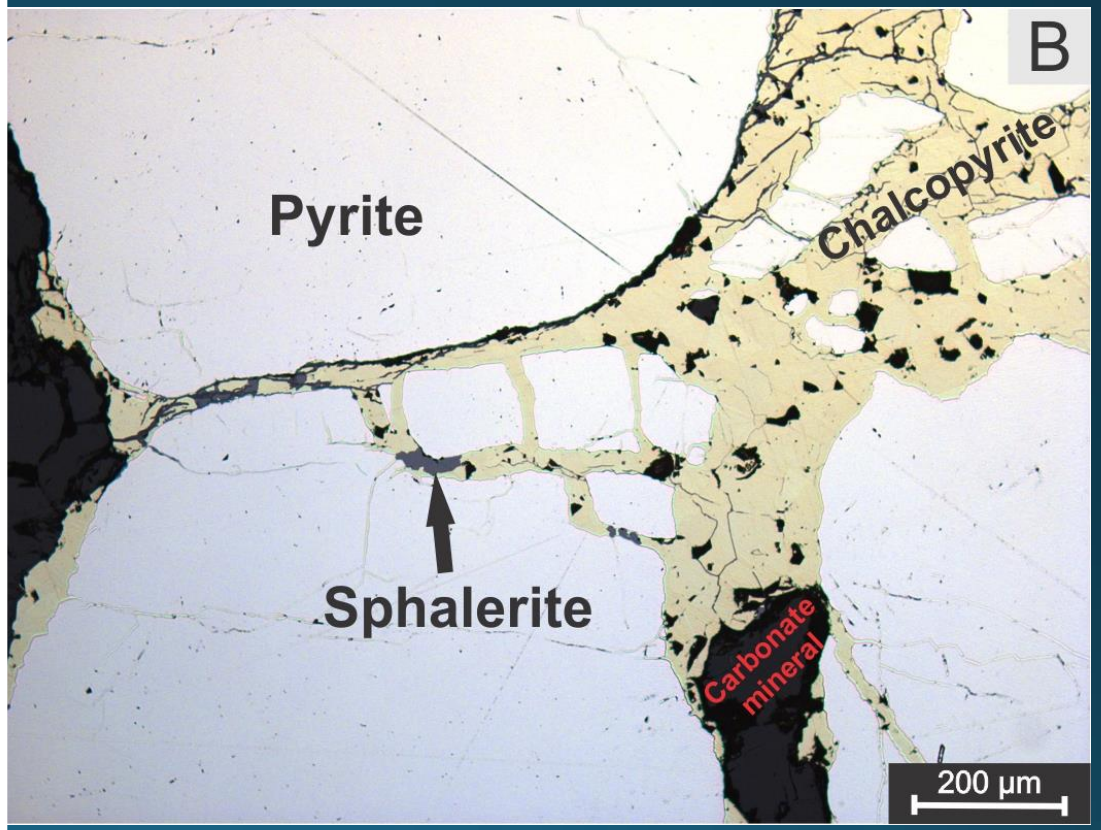
Two types of chalcopyrite in mafic rock-hosted quartz-carbonate veins

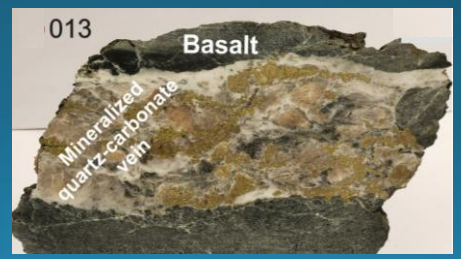
Type 1: Mitchell mine



- Chalcopyrite
- Pyrite

Type 2: Carl Johan mine



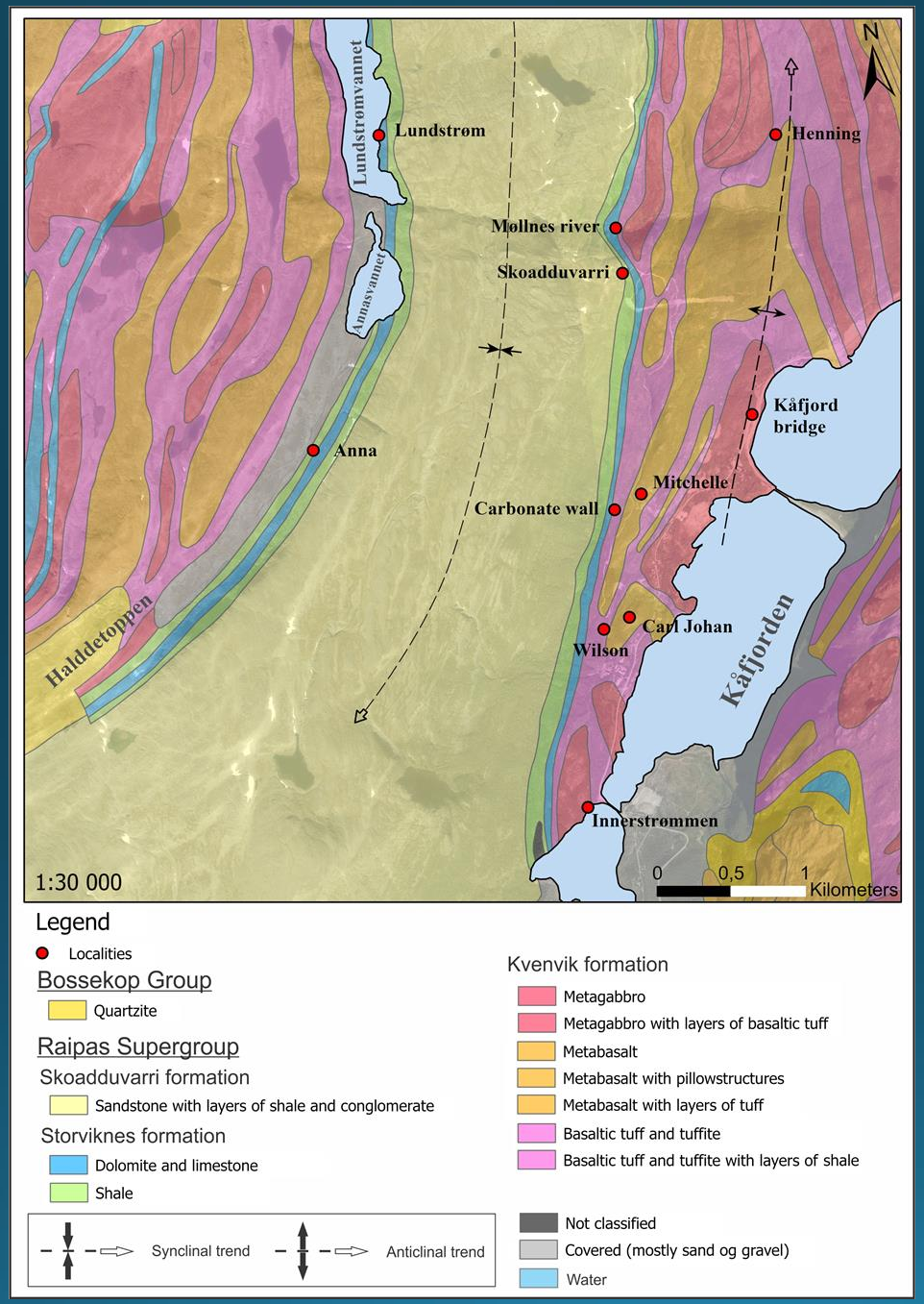


- Chalcopyrite
- Pyrite
- Sphalerite (Zn, Fe)S

Mafic rock-hosted

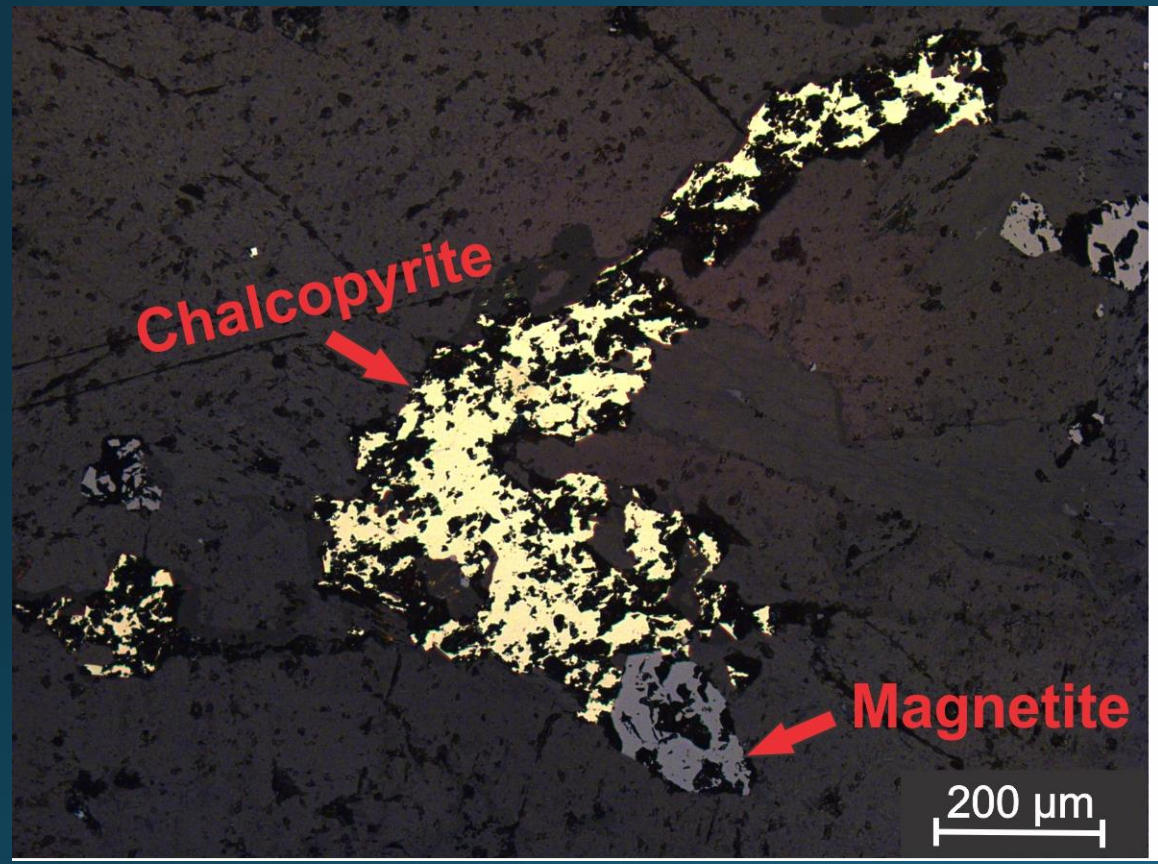
Copper as dissemination in host rock

Kåfjord bridge
(Gabbro hosted)

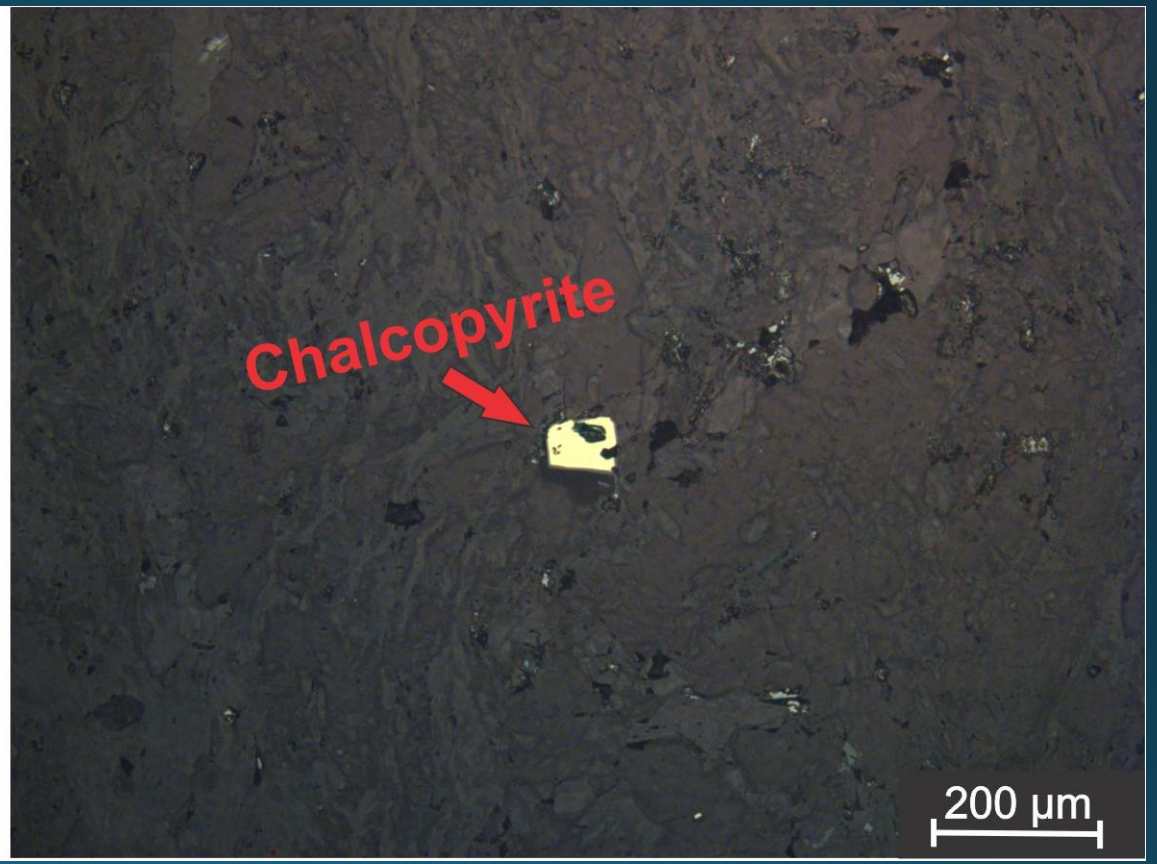


Carl Johan mine
(Basalt hosted)

Host rock chalcopyrite



Chalcopyrite in gabbro at locality Kåfjord bridge

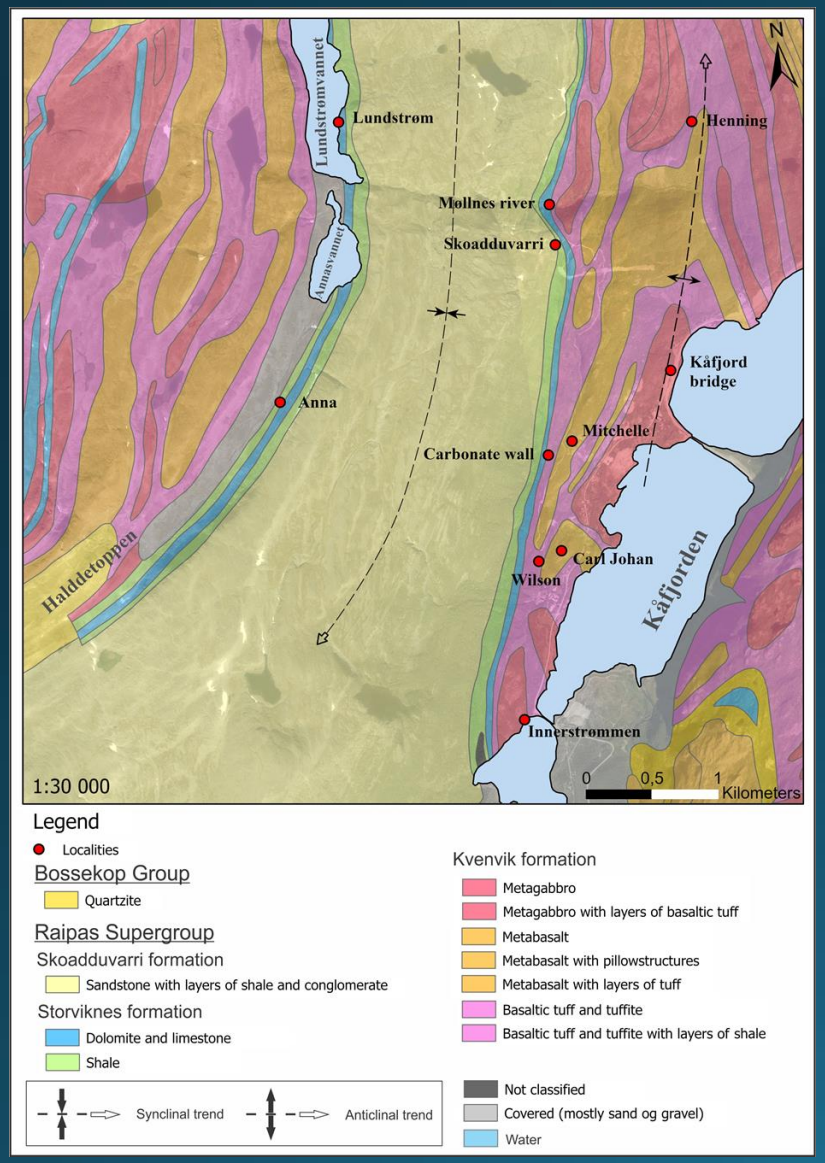


Chalcopyrite in basalt at Carl Johan mine

Mafic rock-hosted
Syngenetic stratiform mineralization

Henning mine

(Hosted by basaltic tuff and tuffite)

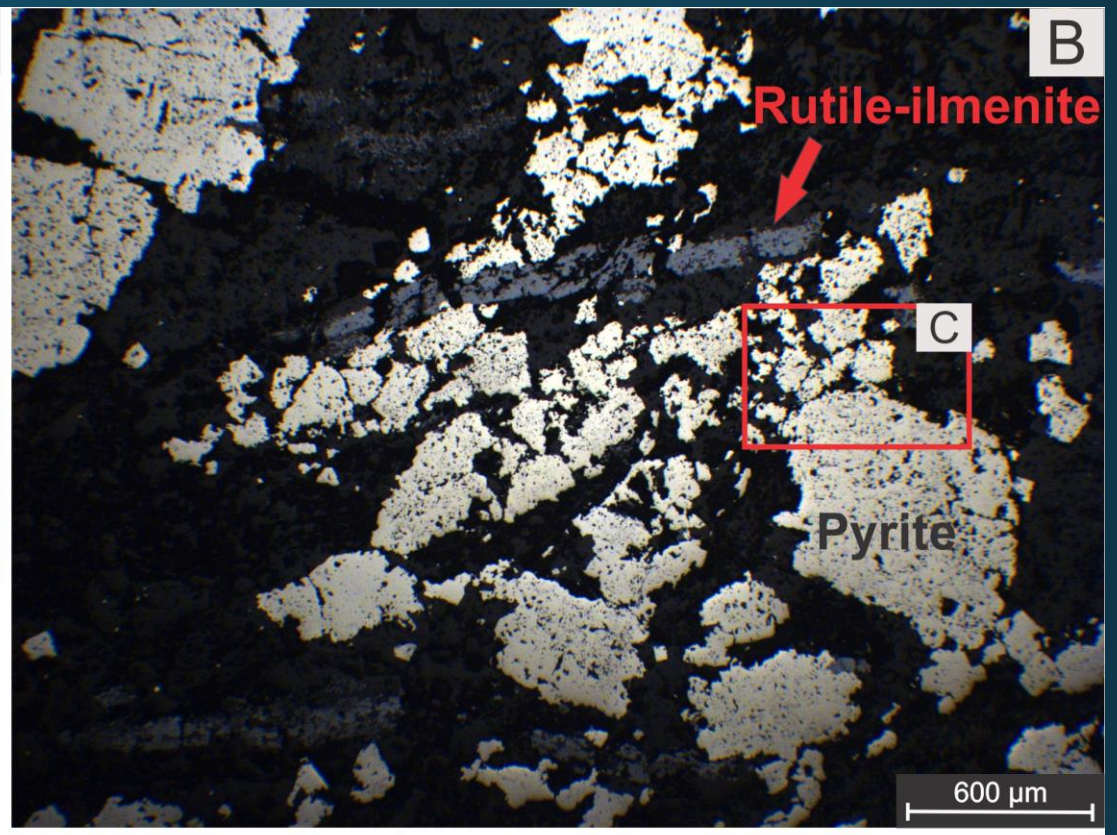


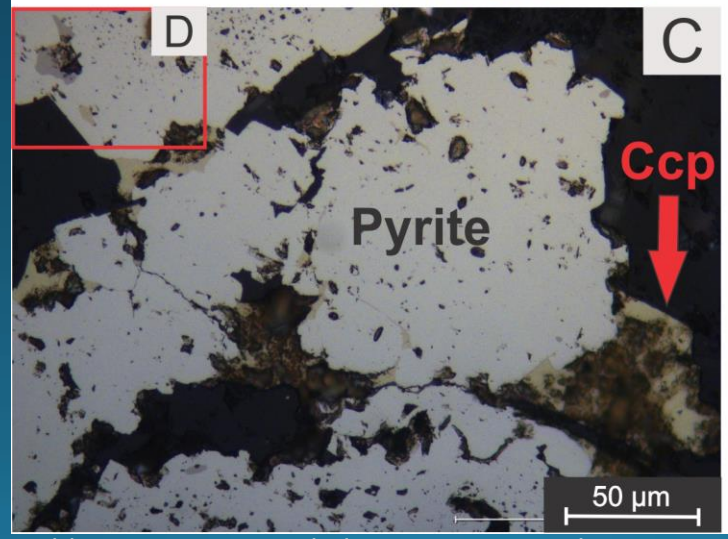
Syngenetic stratiform mineralization

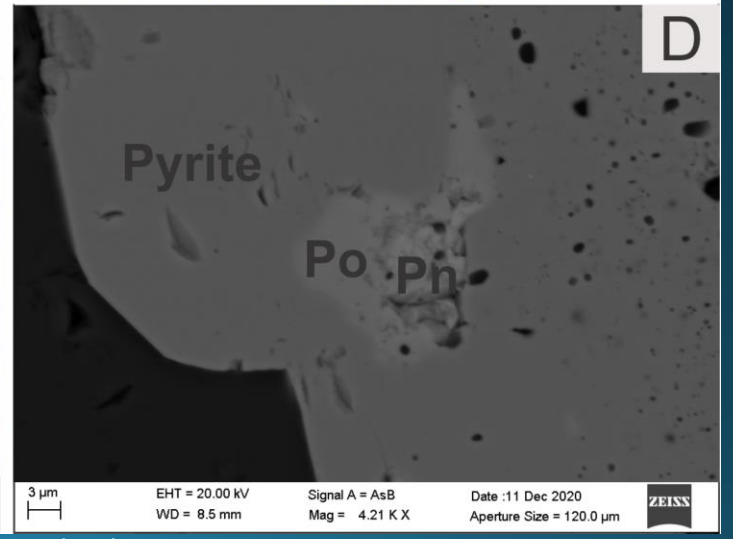
- Pyrite
- Rutile-ilmenite
- Chalcopyrite
- Pyrrhotite
- Pentlandite $(Fe, Ni)_9S_8$

- $\delta^{34}S$ of -16.10 to -16.27 ‰ VCDT

➢ VMS deposit







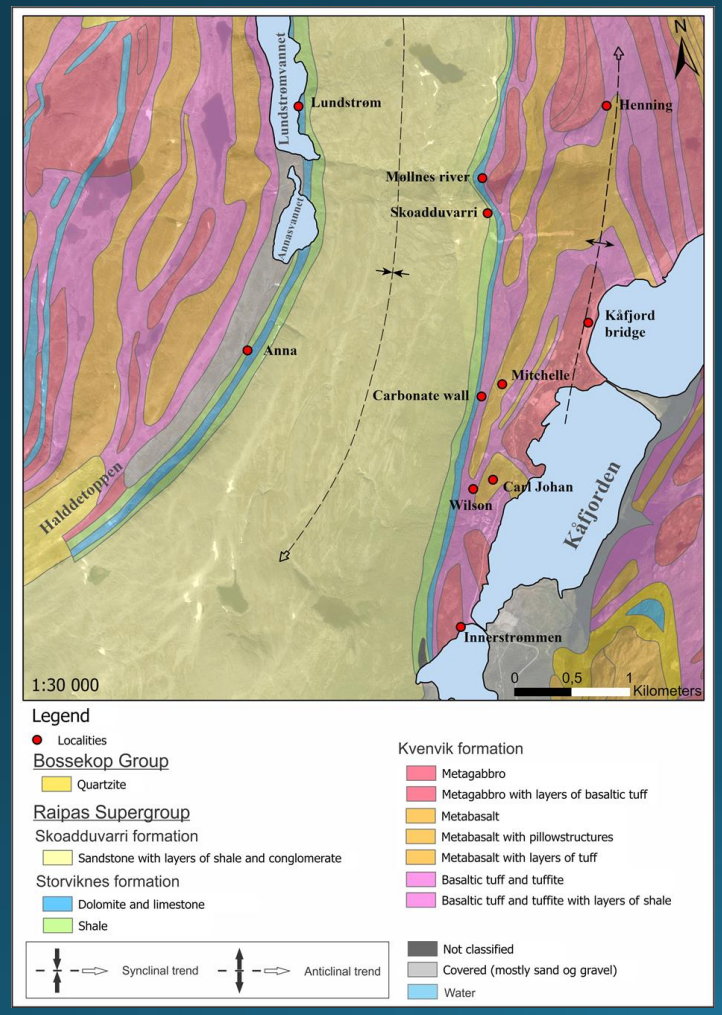
Abbreviations: Ccp: Chalcopyrite, Po: Pyrrhotite, Pn: Pentlandite

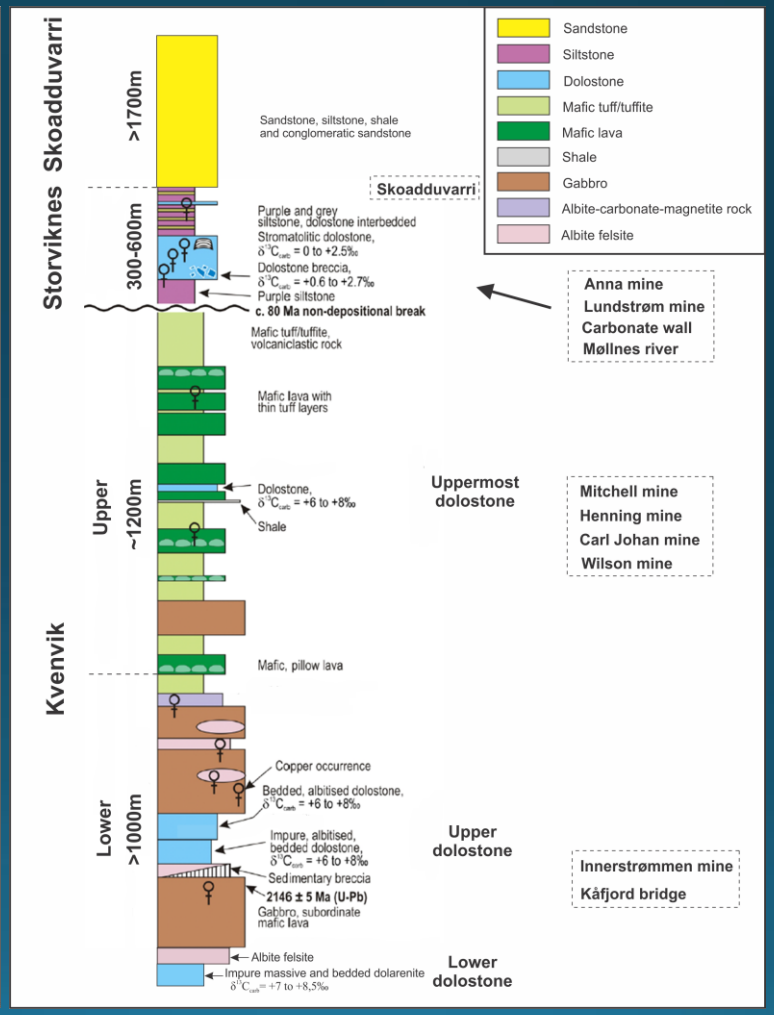
Sediment-hosted

Cu-bearing epigenetic quartz-carbonate veins

Anna mine

(Sediment-hosted)
Outcrop 1



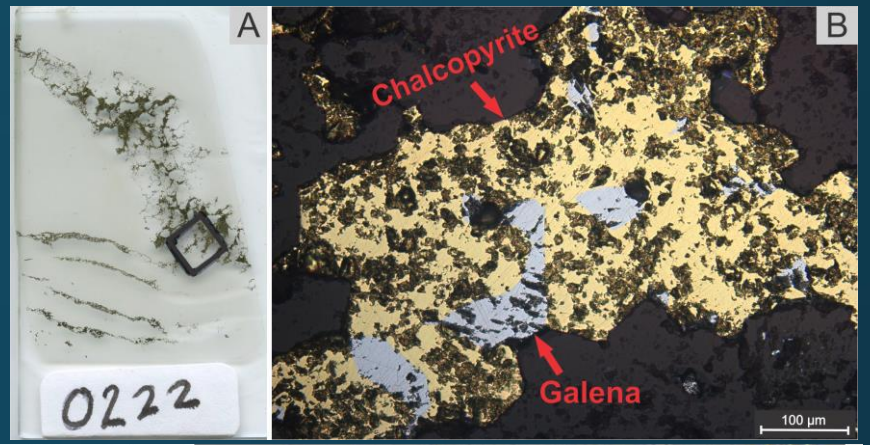


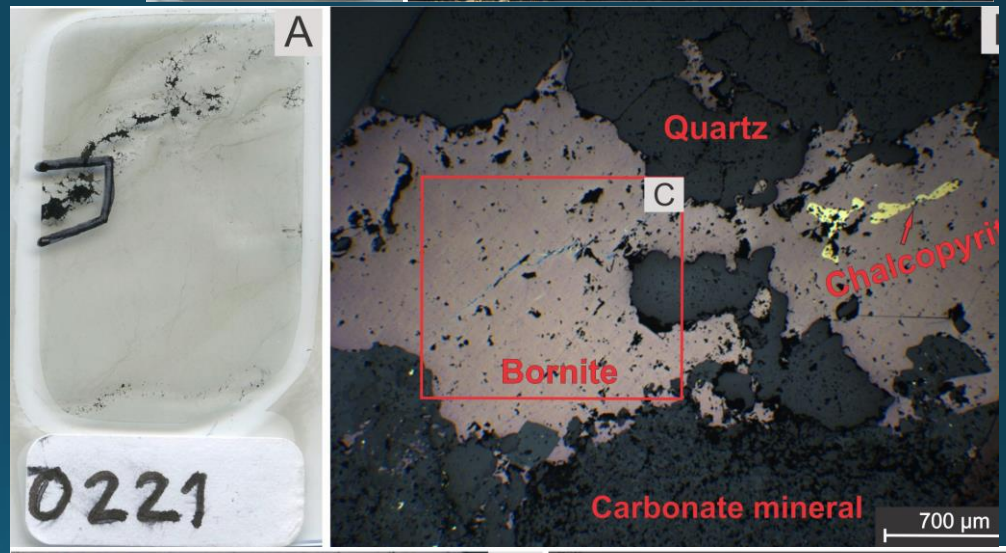
Anna mine

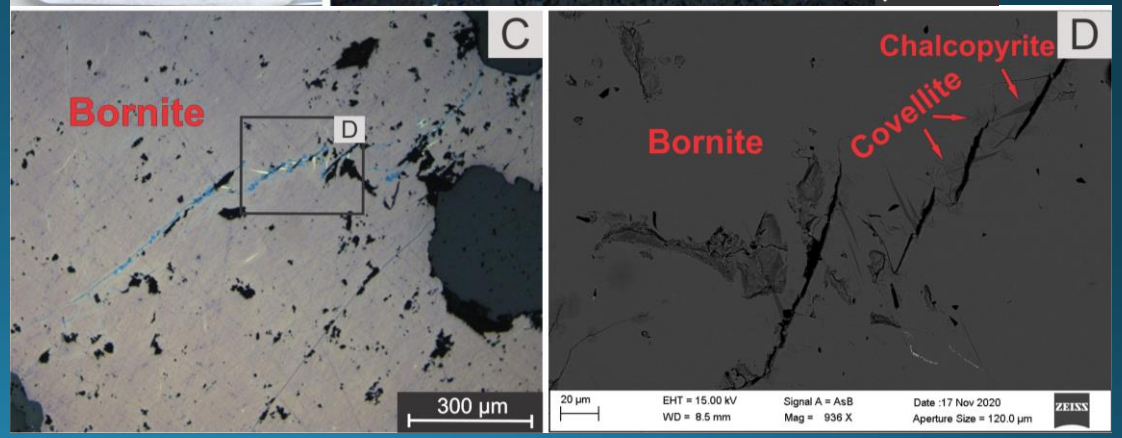
(Sediment-hosted)

- Epigenetic quartz-carbonate veins
- Hosted in carbonate

- Chalcopyrite
- Galena (PbS)
- Bornite (Cu_5FeS_4)
- Covellite (CuS)

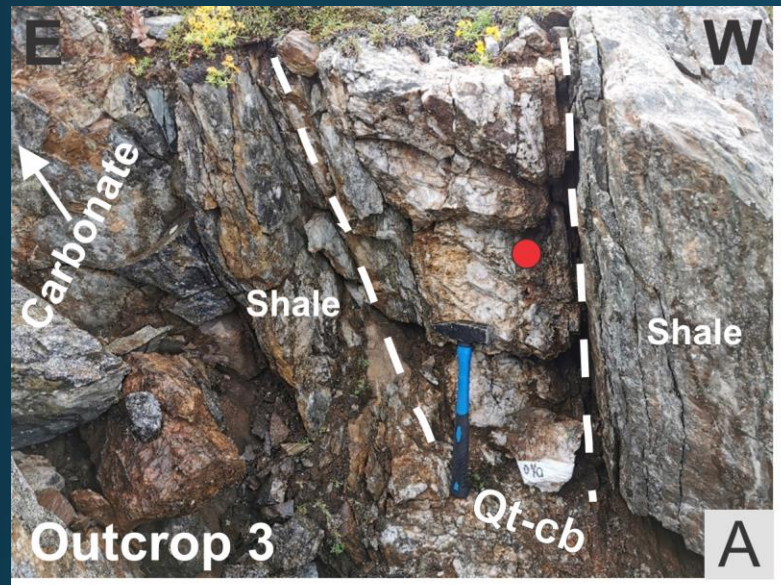


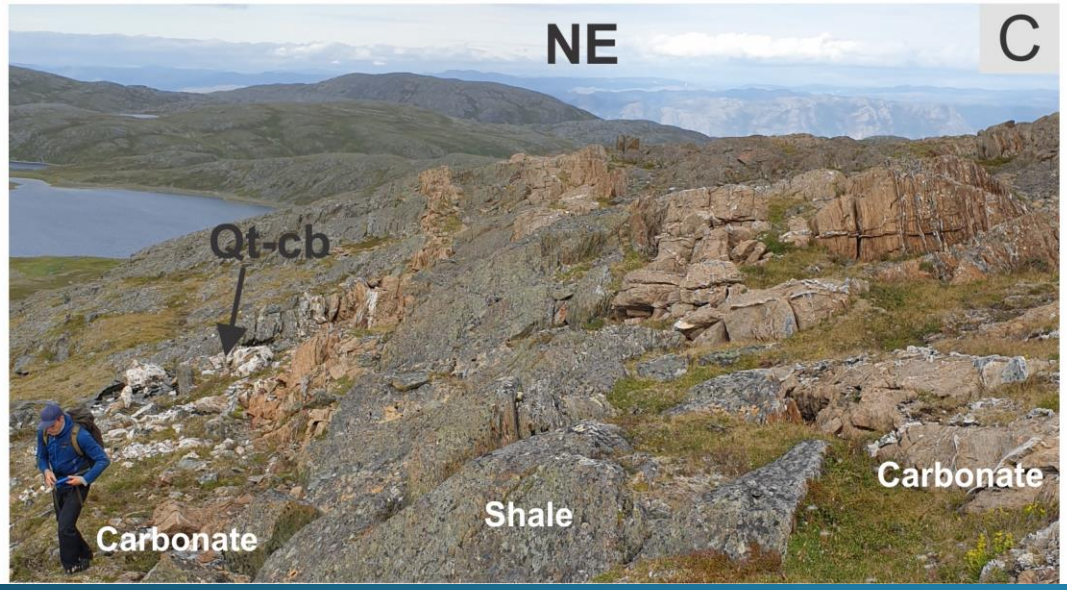




Anna mine

(Sediment-hosted)

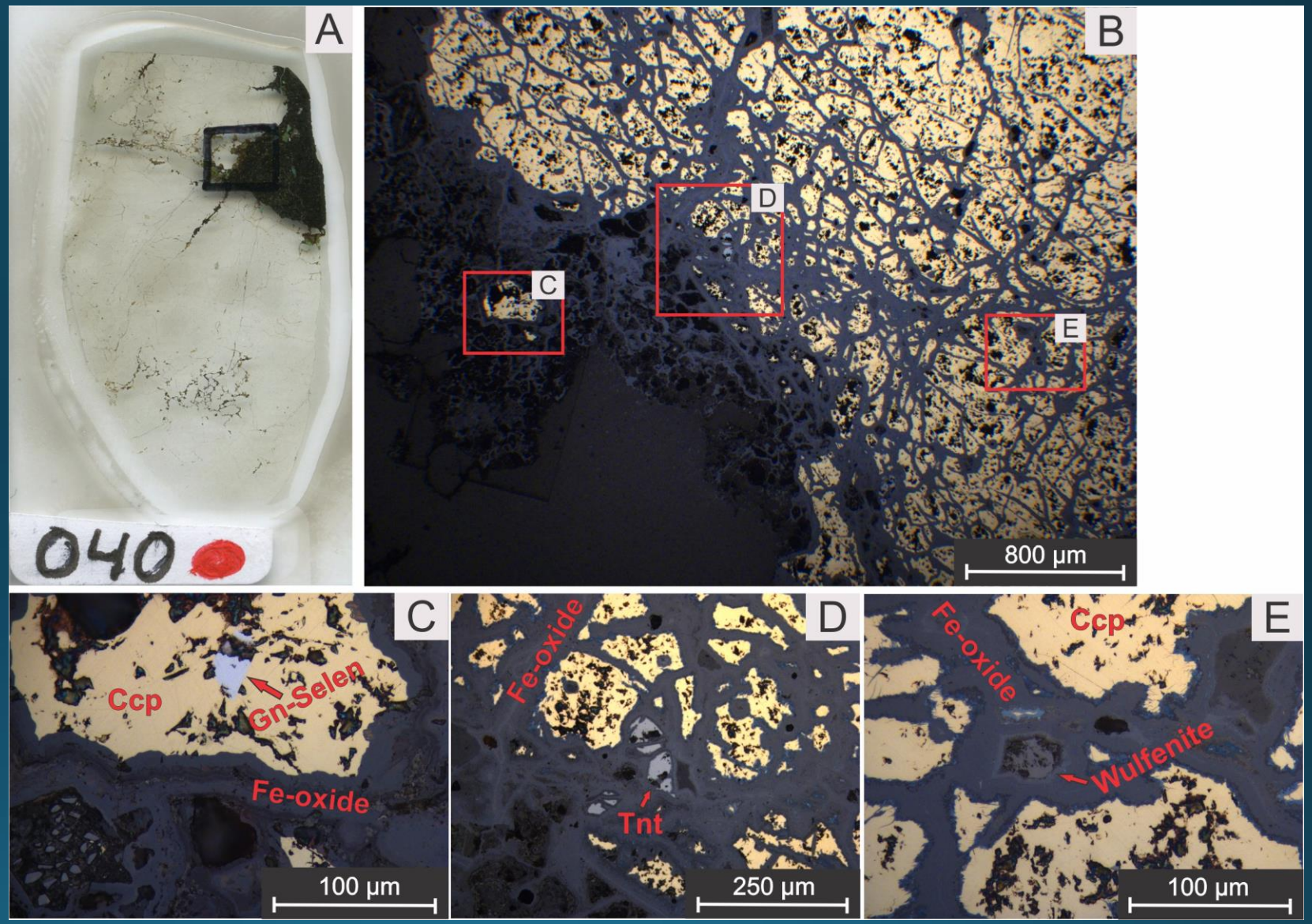




- Epigenetic quartz-carbonate vein
- Hosted in shale

Epigenetic quartz-carbonate vein

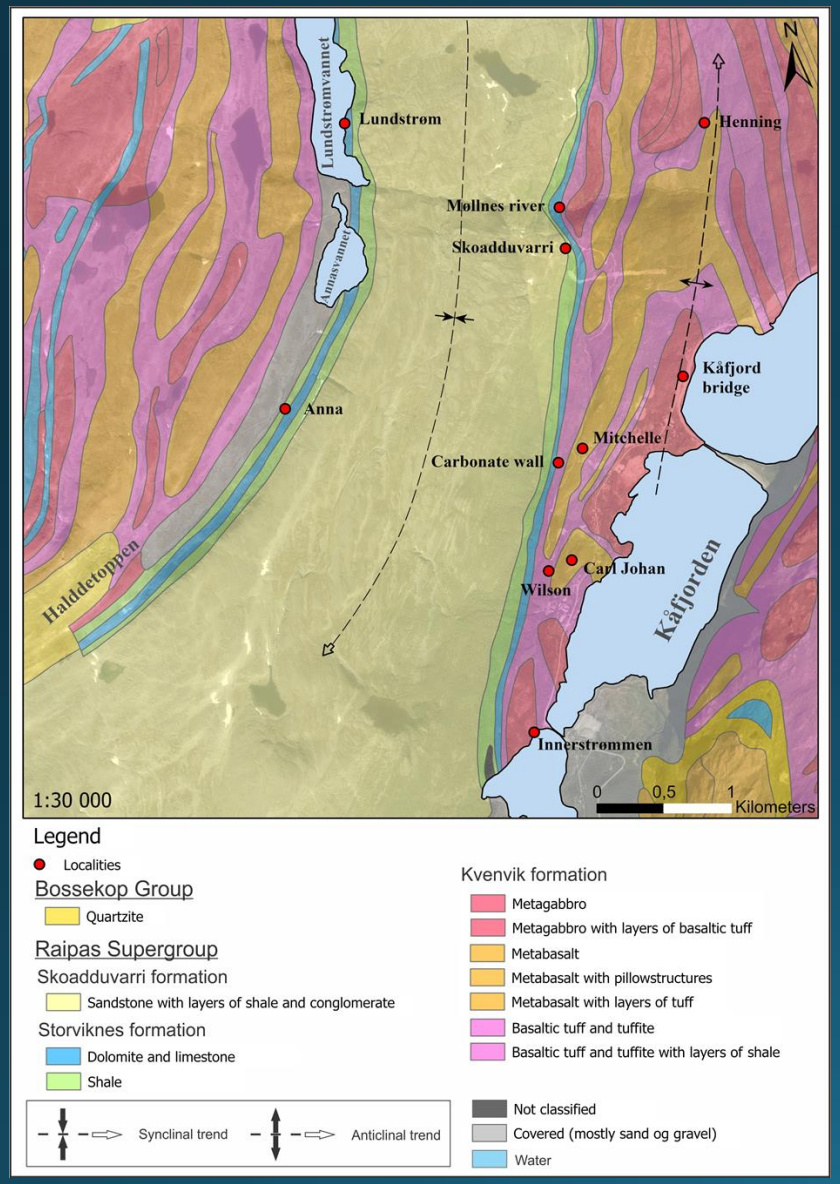
- Chalcopyrite
- Fe-oxide
- Selenium-rich galena
- Tennantite ($Cu_{12}As_4S_{13}$)
- Wulfenite ($PbMoO_4$)



Abbreviations: Ccp: Chalcopyrite, Gn-selen: selenium-rich Galena, Tnt: Tennantite

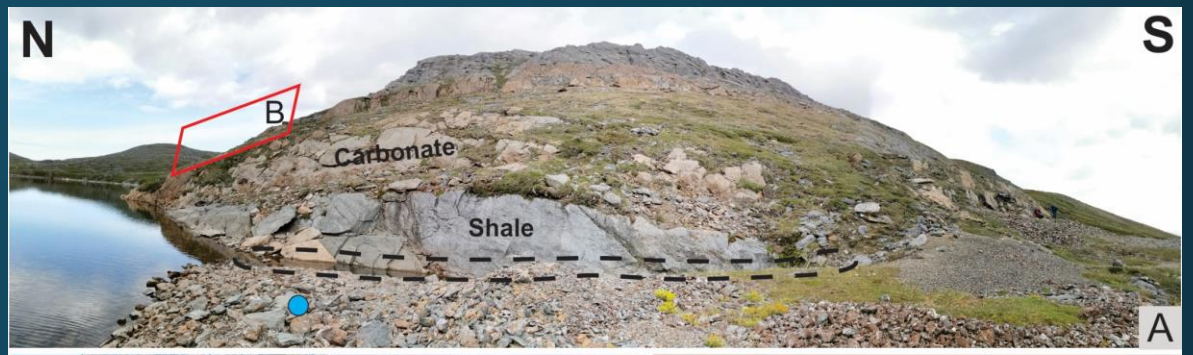
Lundstrøm mine

(Sediment hosted)

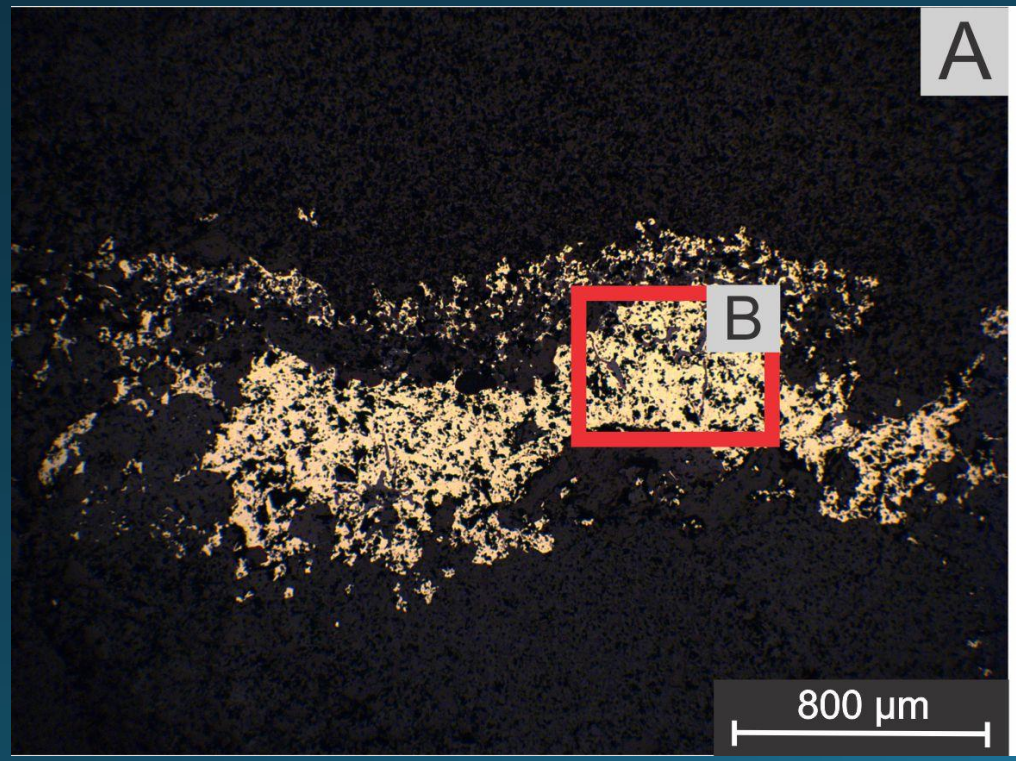


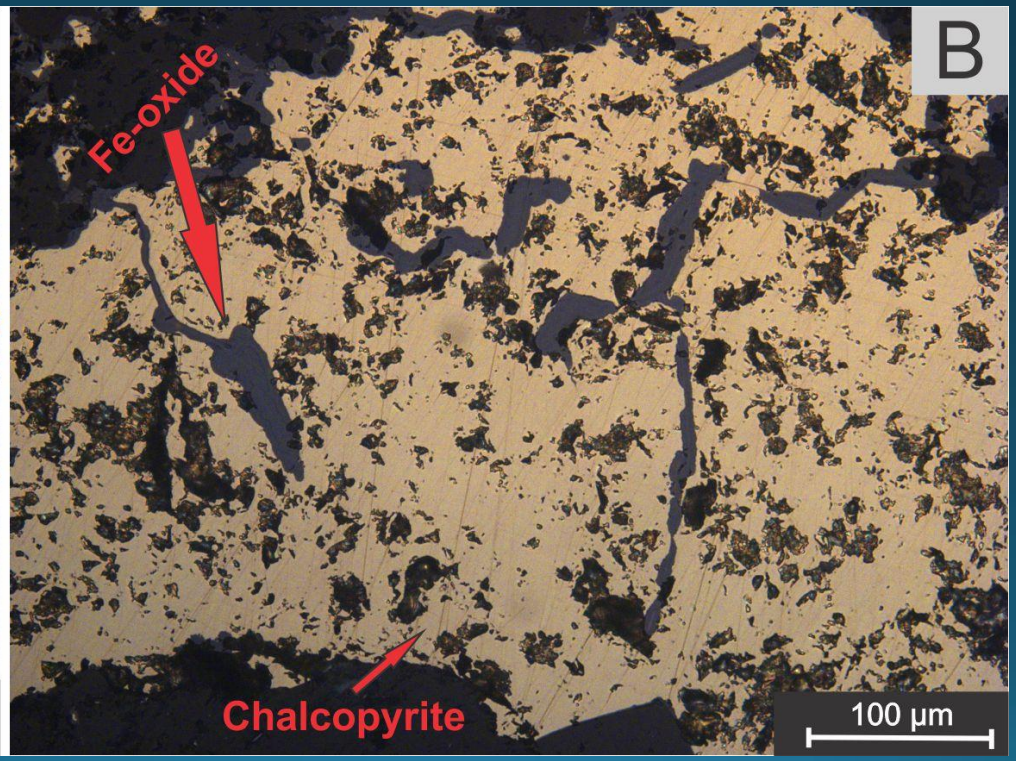
Epigenetic mineralization

- Bedding parallell hosted in carbonate
- Brecciated hosted in carbonate and shale



Bedding parallel, ductile deformed epigenetic quartz-carbonate veins





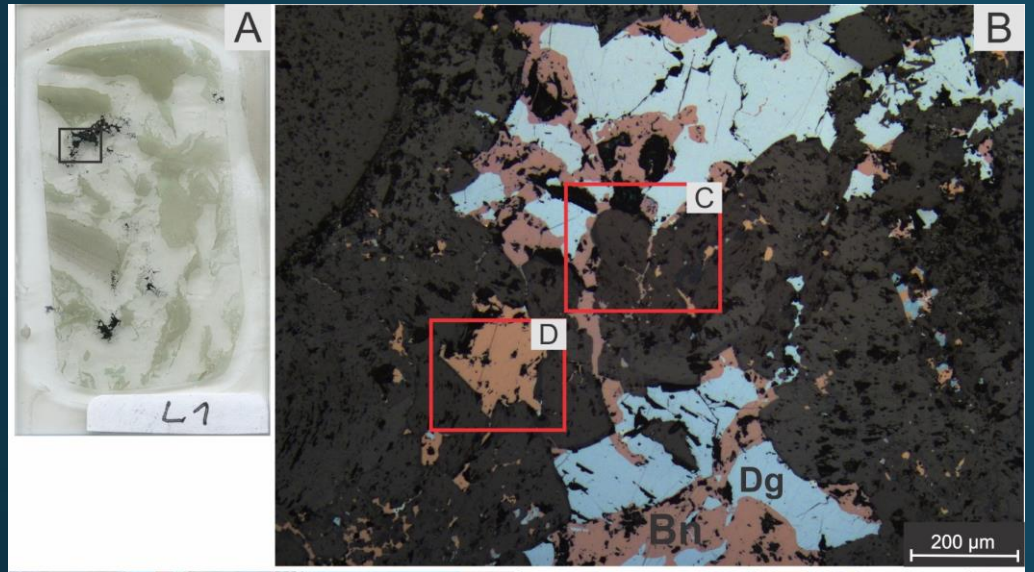
- Chalcopyrite
- Fe-oxide

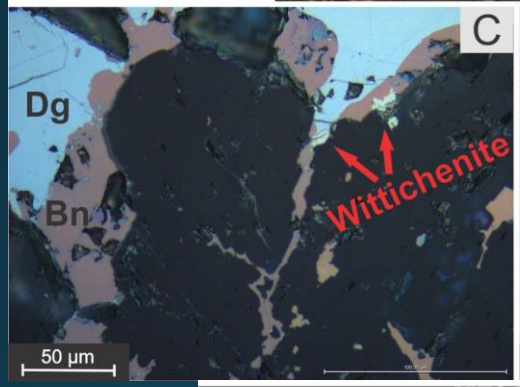
- Hosted in carbonate

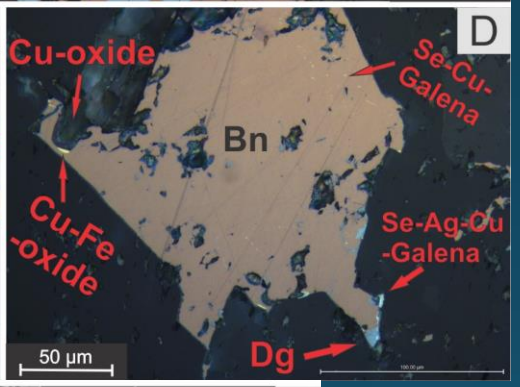
Brecciated mineralization

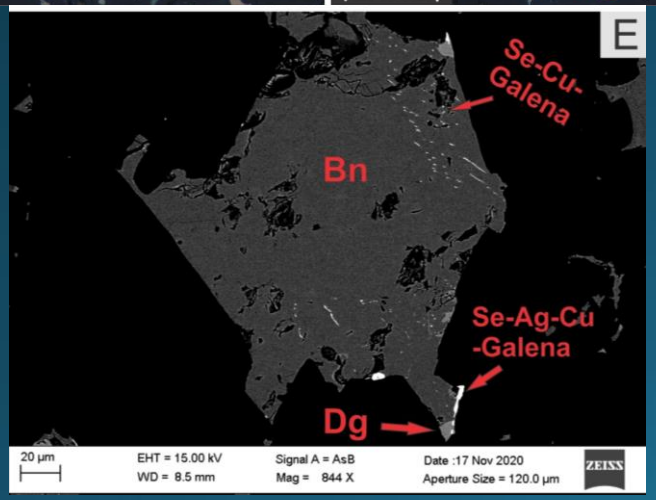
- Digenite (Cu_9S_5)
- Bornite (Cu_5FeS_4)
- Wittichenite (Cu_3BiS_3)
- Selenium, silver, and copper-rich galena
- Selenium and copper-rich galena
- Selenium-rich galena
- Cu- and Cu-Fe-oxide
- Molybdenite (MoS_2)

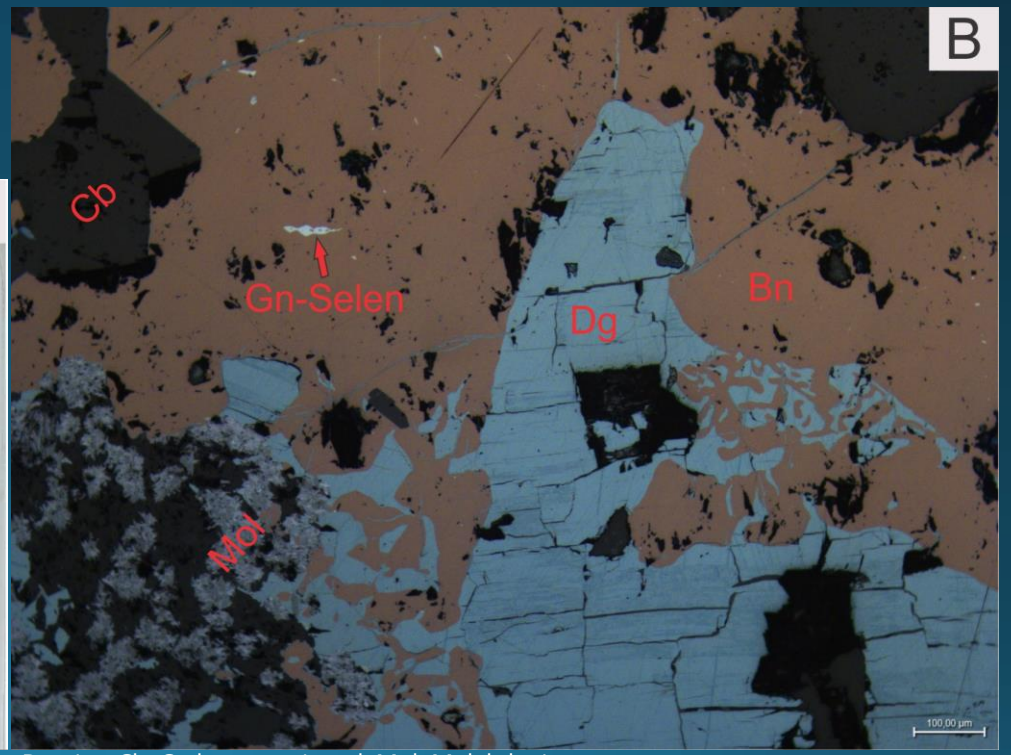
- Hosted in carbonate and shale





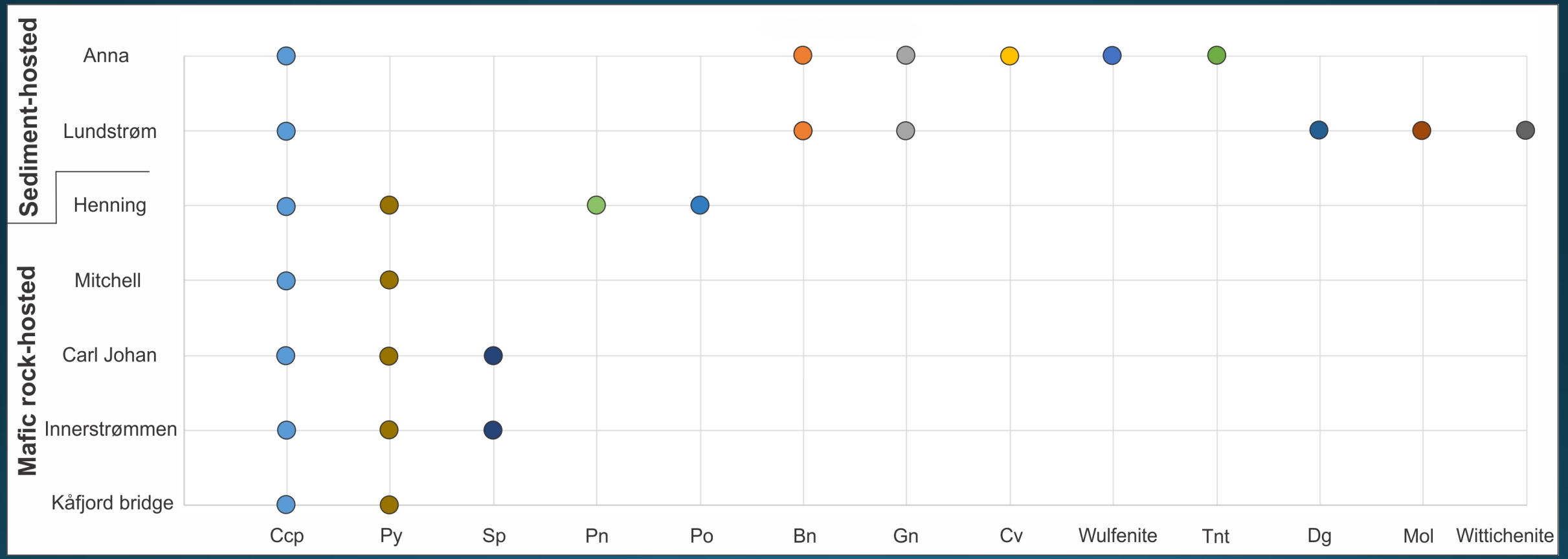






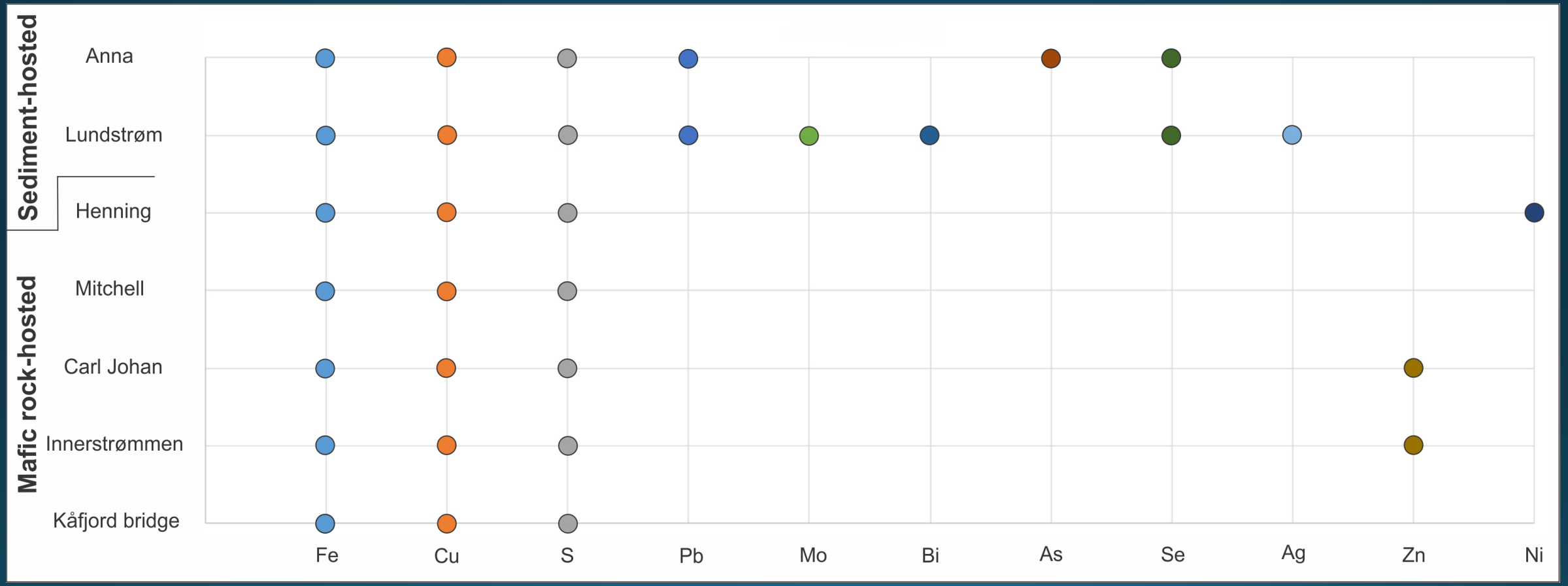
Abbreviations: Dg: Digenite, Bn: Bornite, Cb: Carbonate mineral, Mol: Molybdenite

Ore mineral distribution

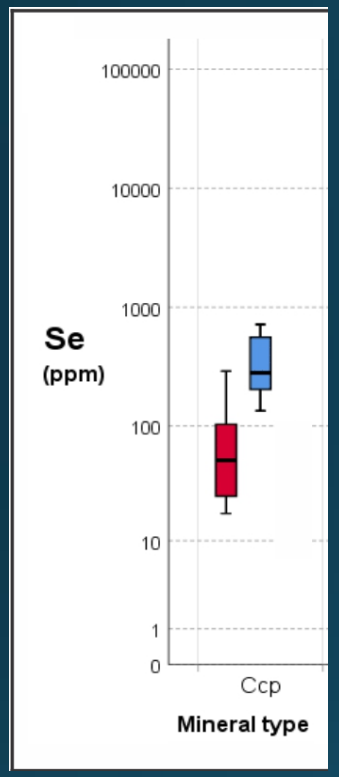


Abbreviations: Ccp: Chalcopyrite, Py: Pyrite, Sp: Sphalerite, Pn: Pentlandite, Po: Pyrrhotite, Bn: Bornite, Gn: Galena, Cv: Covellite, Tnt: Tennantite, Dg: Digenite, Mol: Molybdenite.

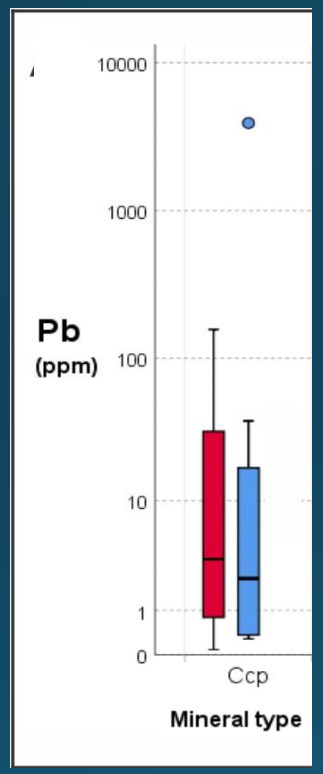
Element distribution



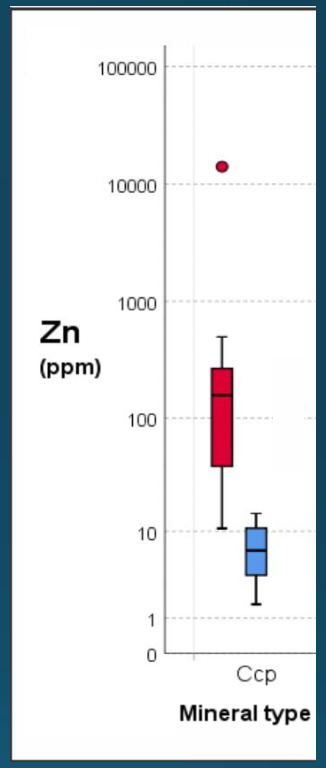
Trace element characteristics of sulfides



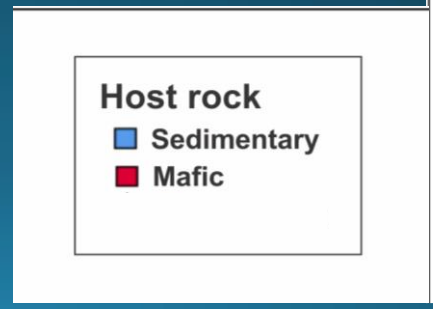
Abbreviations: Ccp: Chalcopyrite, Py: Pyrite, Bn: Bornite.

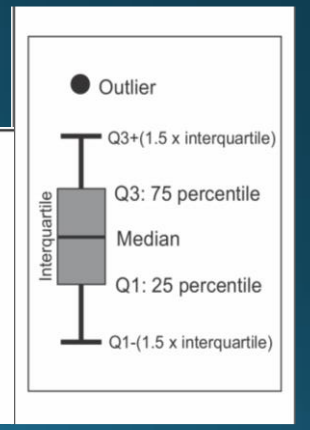


+ Ag, As and Hg



+ Ni, Cr, Sb and Cd





- Storviknes (sediment-hosted) may source of Se
- Kvenvik (mafic rock-hosted) may source of Zn, Ni, Cr, Sb and Cd (including Cu)

Carbonate isotope

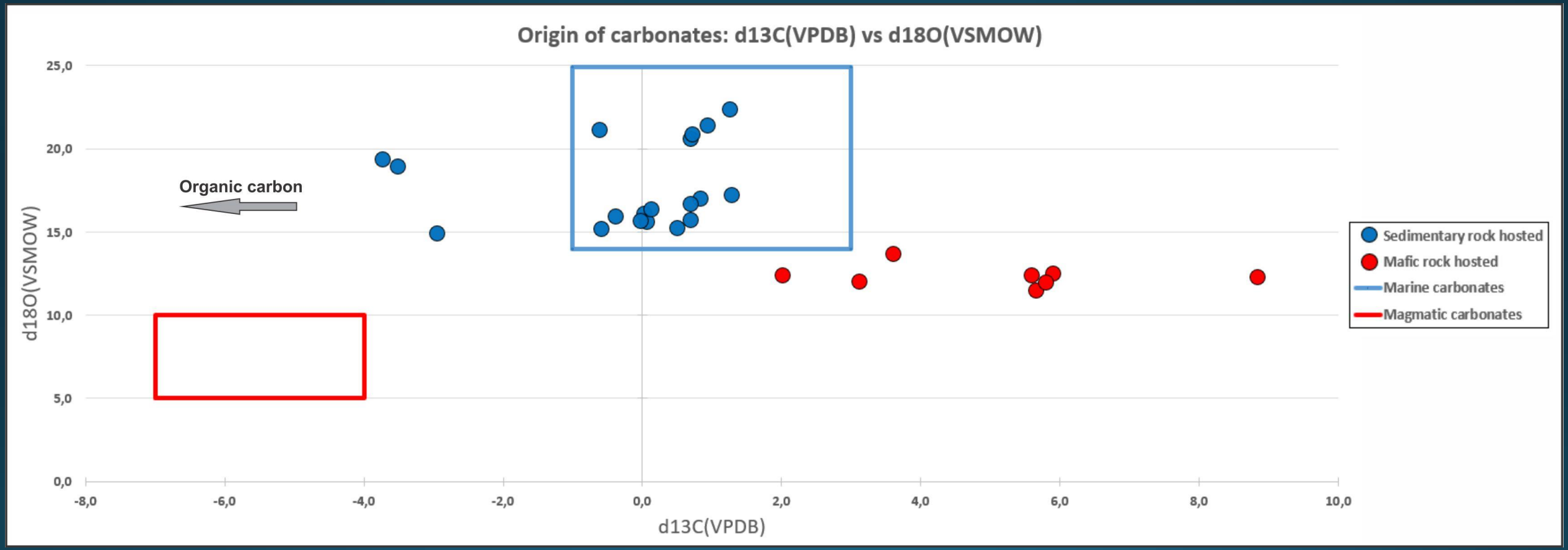


Figure: $\delta^{18}O$ (VSMOW) vs. $\delta^{13}C$ (VPDB) plot. Typical values for marine carbonates are presented by the area of the blue box (data from Veizer and Hoefs (1976)), while magmatic carbonates usually overlap with the values represented by the red box (data from Stakes and O'Neil (1982)). The grey arrow indicates an influence of organic matter. VSMOW: Vienna Standard Mean Ocean Water, VPDB: Vienna Pee Dee Belemnite.

Sulfur isotope

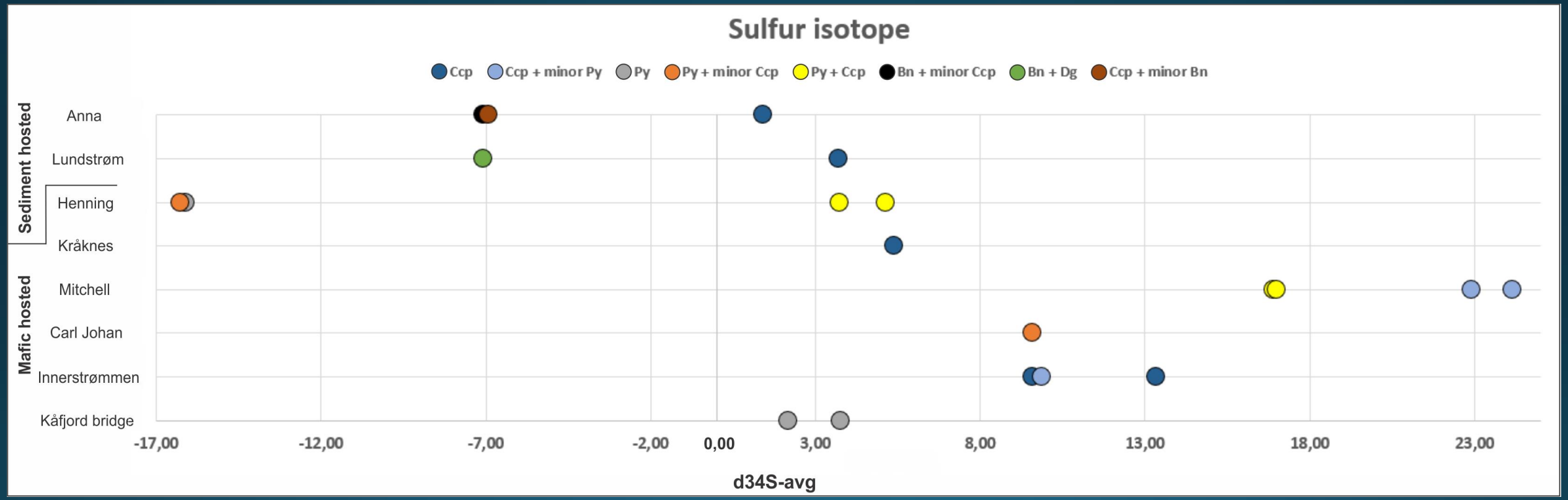


Figure: $\delta^{34}S$ (VCDT) of different minerals plotted against different localities. Some points are of two minerals which are due to intergrowth. Abbreviations: Ccp: Chalcopyrite, Py: Pyrite, Bn: Bornite, Dg: Digenite.

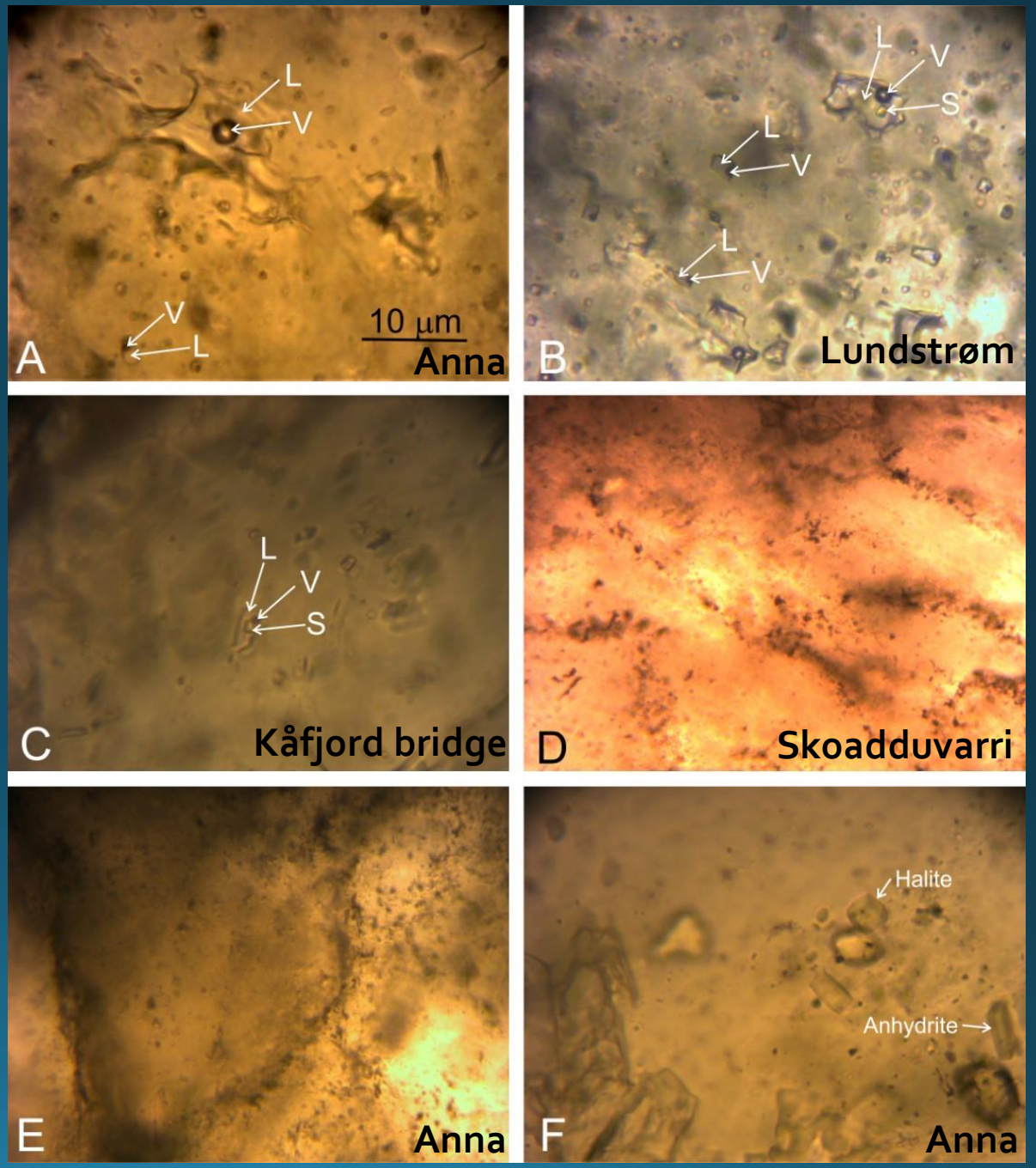
Fluid inclusion study

- 4 fluid inclusion types
  - Type 1: L+V
  - Type 2: L+V+S
    - -> In all mineralized samples
  - Type 3: Decrepitated
  - Type 4: S (halite, anhydrite)

- Highly saline fluid
  - 29.5 to 40,2 wt. % NaCl eq.

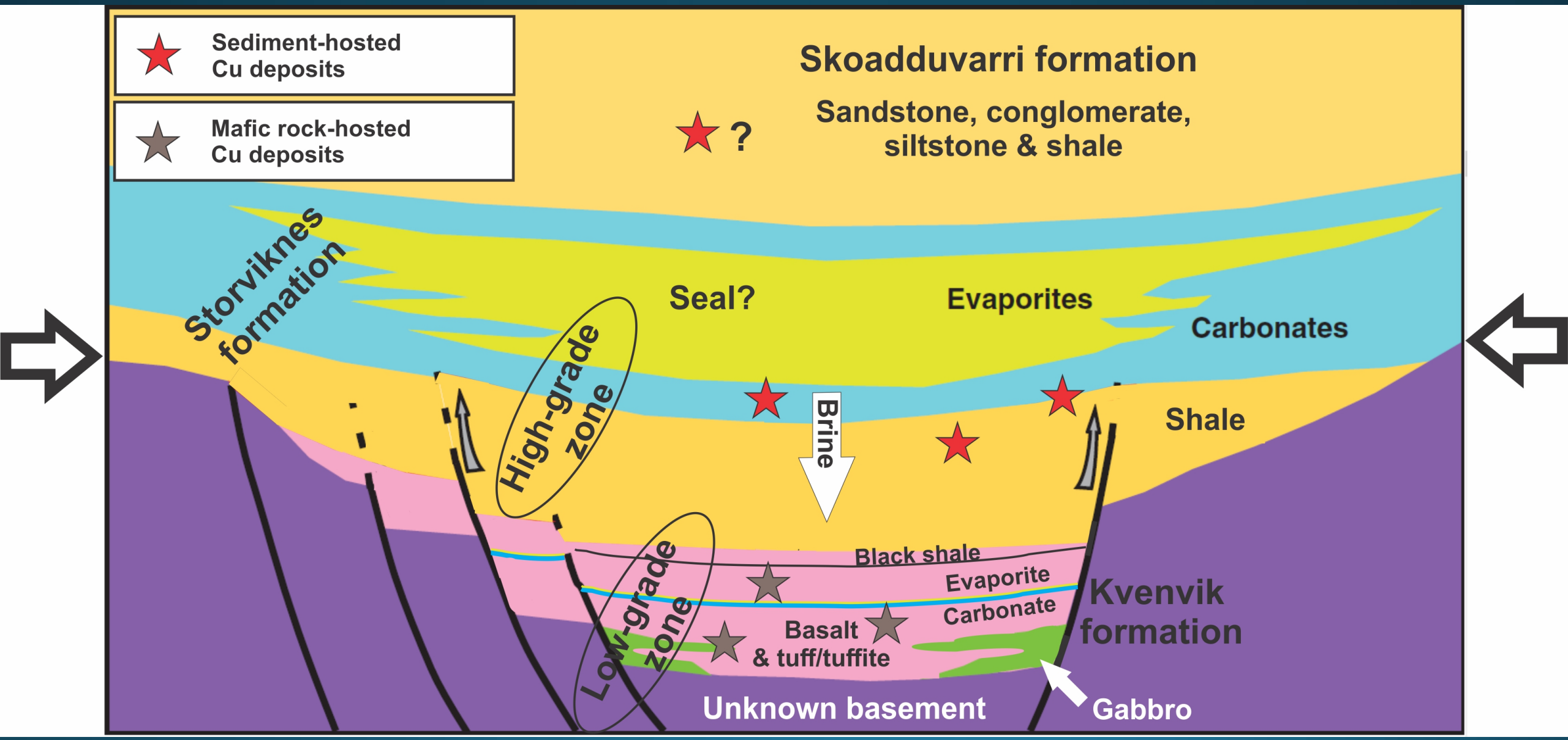
- Low-moderate homogenization temperature
  - Around 200^{0}C

- One ore-forming fluid



Abbreviations; L: liquid, V: vapor, S: solid.

Ore-forming model



Modified from Hitzman et al. (2010)

Conclusion

Conclusion

A total of six main different types of mineralization have been identified within the Kvenvik and Storviknes formation in the area of Kåfjord.

Mafic rock-hosted

Syngenetic (Type 1)

- Stratiform VMS

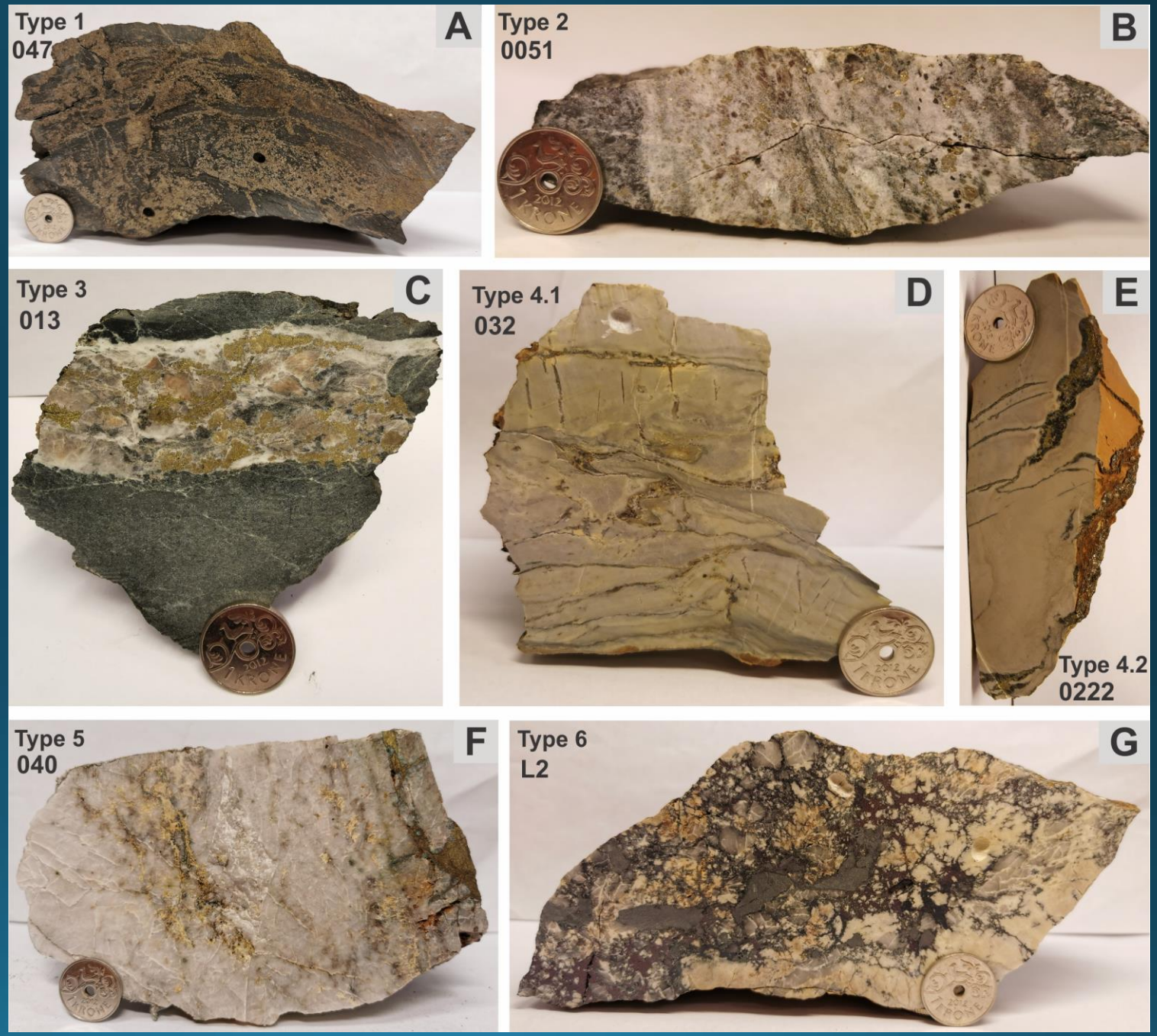
Epigenetic (Type 2 & 3)

- Cu-barren quartz-carbonate vein
- Cu-bearing quartz-carbonate veins

Sediment-hosted

Epigenetic (Type 4-6)

- Cu-bearing quartz-carbonate veins

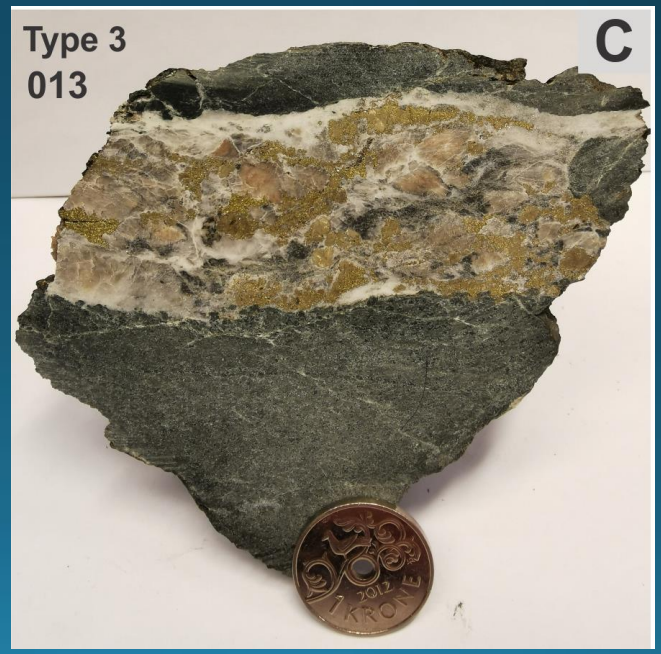


Conclusion

- Mafic rock-hosted syngenetic stratiform VMS deposit are characterized by the mineral assemblage pyrite, chalcopyrite, pyrrhotite, pentlandite and rutile-ilmenite bands, with a strong negative $\delta^{34}S$ composition, revealing an influence of sulfate-reducing bacteria during deposition. It was deposited on the seafloor simultaneous with the Kvenvik formation, with a tholeiitic composition and MORB character confirming earlier studies e.g. Bergh and Torske (1988). A slight depletion in Ce indicates concentration of Ce in ferromanganese nodules on the seafloor.

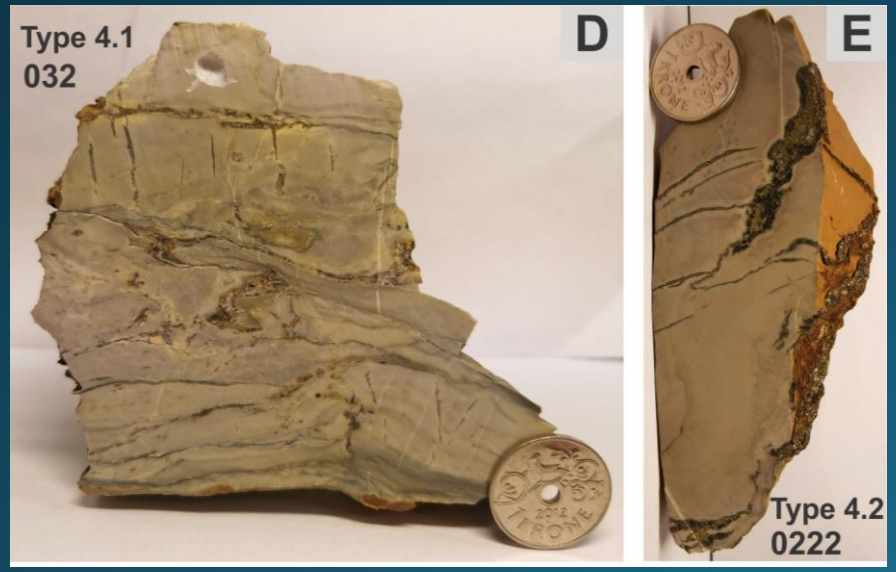
Conclusion

- Mafic rock-hosted epigenetic quartz-carbonate veins within Kvenvik formation are both Cu-barren with pyrite as ore mineral and Cu-bearing with pyrite, chalcopyrite and sphalerite as ore minerals. Textural relationship and trace element distribution divides chalcopyrite into two different types. The mineral assemblage of pyrite and chalcopyrite corresponds to the low-grade zone in a sediment-hosted Cu deposit. The positive $\delta^{13}C$ values in the quartz-carbonate veins have been influenced by carbonate layers formed during the Lomagundi-Jatuli Event. The positive $\delta^{34}S$ values suggests evaporites as a potential source of sulfur.



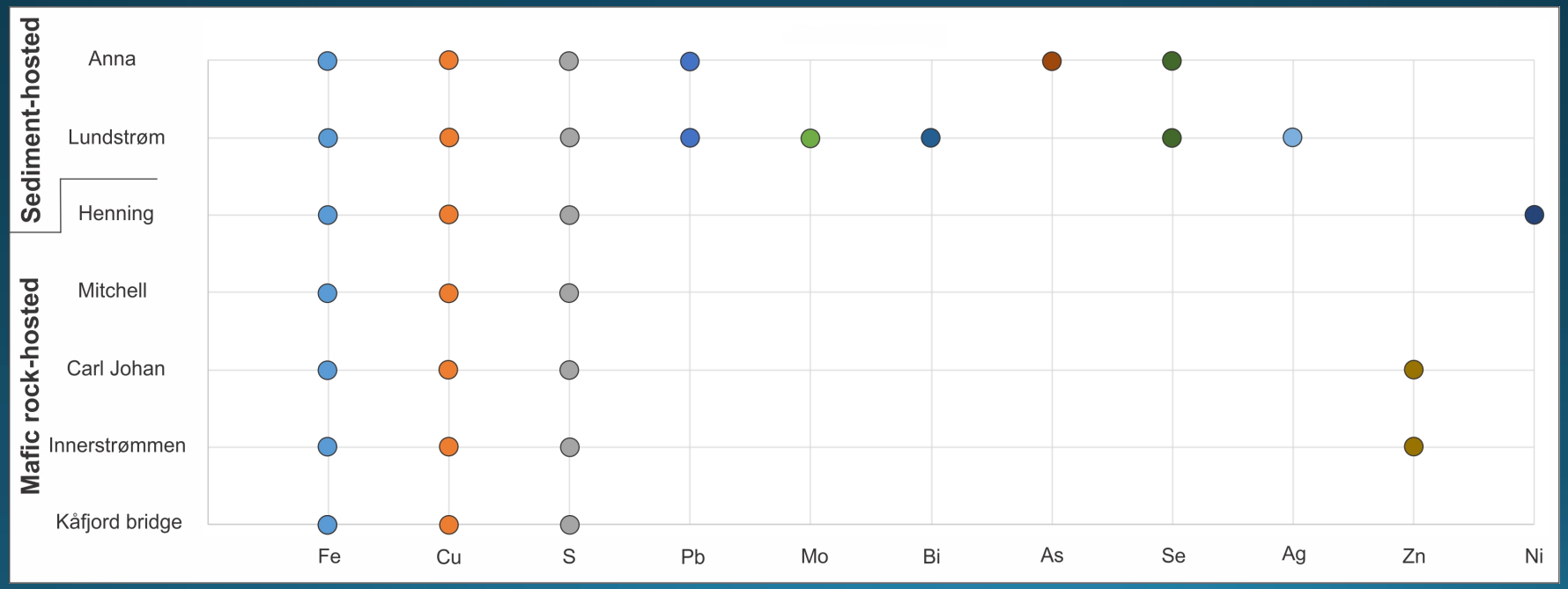
Conclusion

- Sediment-hosted Cu mineralization occurs as three main types of epigenetic quartz-carbonate veins in the Storviknes formation, with a mineral assemblage of digenite, bornite, chalcopyrite, covellite, galena, Se-rich galena, Se-Cu-rich galena, Se-Ag-Cu-rich galena, molybdenite, wittichenite, tennantite and wulfenite. Chalcopyrite from the different mineralization can be partly differentiated by trace element distribution. Cu-rich minerals as digenite and bornite corresponds to the high-grade zone in a sediment-hosted Cu deposit. Most samples suggests marine origin of carbonates, with some samples showing an influence of organic carbon. The noticeable lack of pyrite reflect its replacement by copper sulfides.



Conclusion

- Trace elements in chalcopyrite and Fe-oxide in the sediment-hosted Cu mineralization are characterized by an enrichment of Se compared to mafic rock-hosted Cu mineralization, indicating the sedimentary rocks, in particular shales, in the Storviknes formation are the source of Se. Lead, As, Ag and Mo may also be hosted by the Storviknes formation. Trace elements in mafic rock-hosted mineralization are enriched in Zn, Cr and Ni compared to sediment-hosted mineralization, indicating the source of these elements are the mafic rocks in the Kvenvik formation. This is also partly confirmed by the mineral-phases occurring in the two formations. The source of copper is most likely the mafic rocks of the Kvenvik formation.



Conclusion

- The Cu mineralization has most likely occurred during a single event of fluid circulation which lasted for a longer period. Fluid inclusion study reveals that this fluid had a highly saline and a low to moderate temperature. Such fluids have a good capability to transport Cu in forms of chloride complexes. Trace element behavior also suggests one fluid, affected by different host rocks.